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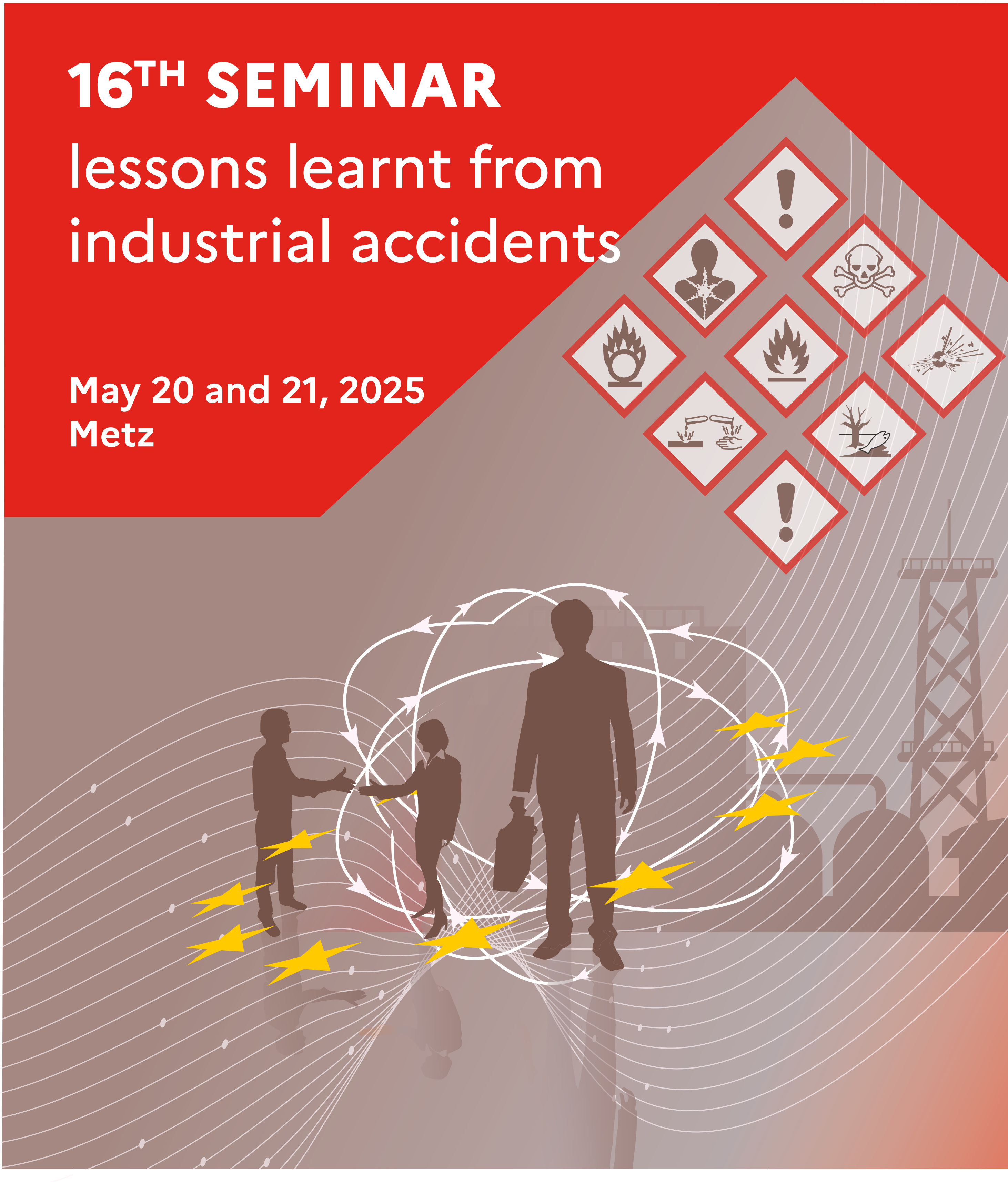
lessons learnt from industrial accidents

May 20 and 21, 2025
Metz



Summary

Lithium batteries - State of accidentology and knowledge

Lithium batteries are bound to play an increasingly important role in the decarbonisation of our economy and the energy transition effort, by enabling massive electrification of uses, especially in the mobility sector, and by supporting the deployment of renewable energies. They also represent an essential component of our everyday life, powering a multitude of domestic appliances. The steep fall in battery prices in recent years, resulting from major technical progress and effects of scale, is making it possible to supply a constantly increasing demand. However, this growth goes hand-in-hand with a significant increase in accident events, particularly in industry. The whole life cycle of batteries is concerned, from their production to their disposal, and including their use, storage, reconditioning or recycling. The analysis of recent accidents, marked by complex large-scale events, reminds us of the need to improve our knowledge of the risks related to lithium batteries.

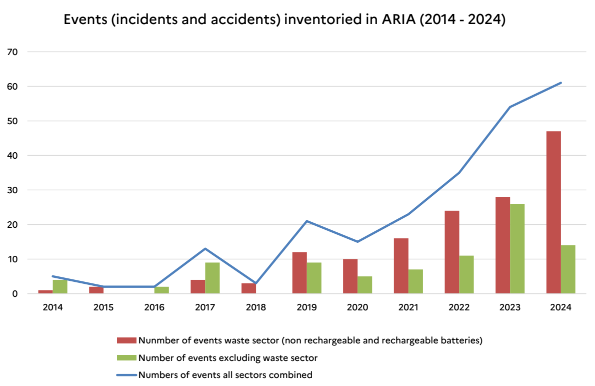
1. Industrial expansion of the lithium battery

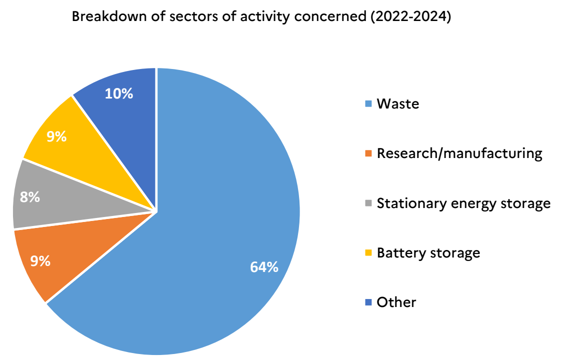
A battery is an electrochemical generator capable of storing energy in chemical form to release it, on demand, in electrical form. It corresponds to an assembly of cells[1] connected with one another to form modules, that can themselves be assembled to form packs, provided with a BMS (Battery Management System). These assemblies depend on the application needs and the required voltage/power levels. Several hundred cells are connected to provide the capacity of an electric vehicle battery pack (about 70kWh), whereas just one is sufficient for smartphones.

The lithium battery now represents around two-thirds of the batteries sold worldwide[2]. This industrial expansion can be explained in particular by the fact that it is this type of battery that now makes it possible to obtain the highest energy densities. Lithium batteries are not only more powerful, but also lighter, which is an essential factor for many applications, from nomad devices to electric mobility. There are at present various lithium battery[3] technologies differing by the type of electrochemically active materials forming the electrodes, but also by the type of electrolyte (organic, solid-state, etc.) used. These factors determine not only the average voltage of the cells but also their scope of application.

2. An increasing rate of accident occurrence representative of the battery's life cycle

The use of electrochemically active materials, presenting risks of exothermic degradation, coupled with increasingly high energy densities, are not without impact on the risks related to the use of lithium batteries. The growing number of uses of lithium batteries, together with the development of all stages of their life cycle (in particular their re-use, recycling, etc.), has gone hand-in-hand with a significant increase in the rate of accident occurrence over the past ten years[4]. This concerns the entire life cycle of the batteries, namely four major types of activities: those manufacturing the batteries and/or performing tests, those which use them as equipment (electric mobility, stationary energy storage, etc.), those which store them (pending diagnosis, reconditioning, etc.) and, lastly, the waste sector when the batteries reach end of life.





More than 60% of the events concern the waste sector. In most cases, the accidental presence of non-rechargeable batteries[5] or rechargeable lithium batteries mixed with other waste is to blame. Outbreaks of fire can occur both in the course of specific operations (crushing, unloading, etc.) and during storage phases (deferred outbreak of fire following an impact, incompatibility with other wastes, short circuit, self-heating, etc.). However, their involvement is still often hard to demonstrate, but is assumed in more than 60% of cases. Note that in terms of hazardous phenomena, this type of event is more like "conventional" waste fires than battery fires (the accidental presence of a lithium battery in a mixture is the source of ignition of the outbreak of fire on a waste heap).

1 The cell, consisting of two electrodes plunged in an electrolyte, is the elementary unit of the battery, the place for electrochemical reactions capable of creating an electric current.

2 Source: les thémas de la DGE (théma n°23 – October 2024).

3 Among the most widespread lithium battery technologies, we can mention in particular LCO, LMO, NCA, NMC, LFP, or again LMP.

4 Data extracted from the ARIA database on 01/04/2025. The number of events identified for 2024 is liable to increase.

5 Non-rechargeable batteries were included in the data extractions relating to the waste sector because in many cases it is impossible to distinguish between accidents relating to non-rechargeable batteries and those of rechargeable batteries (presumed interference, imprecision at the level of the terminology used in reporting, etc.).

For the other activities concerned (excluding the waste sector), an analysis of accidentology identifies events that can occur in very different contexts and circumstances: manufacturing (ARIA 33658, 56182), connection (ARIA 56442), miscellaneous tests (ARIA 45807, 46083, 50033, 54531, 55142, 57677), use (ARIA 54822, 57740, 58857, 58953), routine operations such as charging (ARIA 36215, 54261, 54538, 59745), restarting (ARIA 58516), handling (ARIA 49658) or else storage of new and used batteries (ARIA 50152, 60243, 61711). Note that, although it can be asserted that most events originate in a phenomenon of thermal runaway, the exact cause of this is often hard to determine.

3. Multifactorial hazardous phenomena which are still hard to comprehend

Apart from electrical risk which is always present because inherent in the (new or used) battery itself, the main danger in the event of malfunctioning is thermal runaway. This phenomenon, which could occur during phases of operation or not, may be due to loading of the battery outside of its nominal operating range or mechanical, electric or thermal harm to the system (impact, deep discharge, overcharging, short circuit due to a manufacturing defect, abnormal wear, abnormal ambient conditions, presence of water and humidity, etc.). These disturbances will cause an excessive rise in the temperature of a cell, the effects of which will spread to the entire battery. Thermal runaway is characterised in particular by degradation of the materials forming the battery in the form of exothermic reactions, contributing to a rise in temperature and pressure (gas emissions, usually flammable), and which may cause phenomena of overpressure, fire or else explosion.

Fire is the predominant hazardous phenomenon (95% of events); it is associated with explosions in about 15% of cases (ARIA 60556, 61022). The analysis of accident research identifies complex hazardous phenomena with multifactorial characteristics (type of batteries, charge level, degree of confinement of the enclosure, layout, etc.), making them extremely difficult to comprehend: unpredictable extension of the accident, persistence of hot spots (ARIA 56442, 60556), or again risks of resumption (ARIA 58361, 59149, 60880). Moreover, their high intensity and the associated impacts, especially thermal impacts (ARIA 54261, 60049) and mechanical impacts (ARIA 58361, 60049, 61022, 61579), are liable to make a major contribution to their propagation and consequences.

FACT SHEET

4. Focus on battery storage and stationary energy storage activities

4.1 Recent large-scale events

The stationary energy storage and (new and used) battery storage activities are key sectors, destined to expand massively due to growth in renewable energies and the rapid development of electric mobility, respectively. These activities can lead to large-scale events in case of malfunctions (ARIA 59149, 60243, 60556, 61022, 61711). Between 2020 and 2024, the BEA-RI (Bureau d'Enquêtes et d'Analyses sur les Risques Industriels, i.e., industrial risk investigation and analysis bureau) initiated 6 investigations in order to draw lessons about the risks involved in these activities.

4.2 Accident research which calls into question the effectiveness of fire prevention and safety systems

The analysis of accidentology in these sectors highlights problems of intervention, related in particular to safety and protection barriers which may prove rather ineffective:

- conventional fire detection systems (smoke, temperature) appear unsuitable for detecting internal overheating in batteries, which raises questions about the early detection of outbreaks of fire;
- although automatic extinguishing systems by injection of inert gas or sprinkling can combat external outbreaks of fire on batteries, they are generally unable to put out a cell or a module on fire in the case of a thermal runaway. However, accidentology and tests performed as part of the BEA-RI investigations tend to show that, on certain conditions (early tripping, battery arrangements, etc.), sprinkling can effectively limit or slow down the spread of a battery fire;
- smoke control systems may prove rather ineffective due to stratification of the smoke (particularly in the case of stationary energy storage in containers), between smoke emitted by thermal runaway (white smoke, cold and of high density) and smoke arising from combustion.

While the best means of extinction to cope with thermal runaway is flooding, that is generally hard to employ in the case of stationary energy storage and large-scale battery storage activities. With regard to stationary energy storage, therefore, one notes two intervention strategies employed by the emergency services: spray massively (ARIA 60556) or let the batteries burn while controlling the risk of spreading (ARIA 61022). Note that due to the intensity of the hazardous phenomena and the sometimes large quantities of energy to be dissipated, these events lead to very long interventions (several days), even in the case of massive spraying with water. In the case of massive spraying with water, it should be noted that the container opening phase is a tricky operation due to the risk of backdraft, and that the quantities of water required may prove very substantial.

Fire at a used LMP battery storage warehouse

16/01/2023

Grand-Couronne (Seine-Maritime)

France

Battery
Lithium
Warehouse
Fire

THE ACCIDENT AND ITS CONSEQUENCES

At around 4.30 p.m. on Monday 16 January 2023, in a logistics warehouse, technicians detected a bright light and an outbreak of fire on a storage rack for used lithium battery modules. The logistics warehouse in question consisted of 4 storage compartments which the operator leased to businesses. The outbreak of fire occurred in compartment 1 in which were stored several thousand used batteries of the Lithium-Metal-Polymer (LMP) type.

Given the scale of the fire as of the first minutes, those present did not intervene. They called the public emergency services and gave instructions to evacuate the premises. The fire developed and became very intense, fuelled first by the batteries, and then by the stock of tyres present in the adjacent compartment and by combustible products present in a third compartment. The fire would be declared extinguished on 18 January at 10.30 p.m. after a long monitoring phase. Compartments 1 to 3 were completely destroyed. Compartment 4 was preserved from the flames.

During the fire, a cloud of smoke 7 kilometres long was emitted. Measurements were taken during the fire and on the following days, without ever detecting abnormal values outside the site in relation with the fire: fine particles (PM 10 and PM 2.5), NOx, CO, H2S, BTEX VOCs, PAHs, deposition of soot. The firefighting water had been pumped insofar as possible from the evening of the outbreak of fire, resulting in the recovery of about 12,000m^3 of water, which was then treated by reverse osmosis before being discharged into the natural environment.

The main consequences of the fire, apart from the destruction of the merchandise present in 3 of the 4 compartments and the resulting business disruptions for the 3 lessee companies, were the emission of a smoke cloud during the fire, the presence of some fallout in the immediate vicinity of the storage centre, contamination of the groundwater by lithium, and the cost of remediation of the accident, far exceeding a total of €10m.

THE ORIGIN AND THE CAUSES

The evidence collected during the investigation conducted by the BEA-RI (Bureau d'Enquêtes et d'Analyses sur les Risques Industriels, i.e., industrial risk investigation and analysis bureau) reveals that the battery modules stored in this storage centre were used modules of the LMP technology withdrawn from circulation for numerous reasons (vehicle withdrawn from circulation, decline in the performance of the module, module failure, or preventive recall operation decided by the manufacturer). The starting point of the accident sequence has not been formally established at this stage. An expert legal appraisal is in progress at the request of one of the building tenants. However, several indications, collected notably by the BEA-RI, have made it possible to identify with a high level of certainty the following facts:

- the reported indications (muffled sounds, no warning sign) and the kinetics of the fire's development are correlated with the observations made during tests conducted in the course of the investigation;
- the tests showed that thermal runaway on a single module could cause widespread fire on the storage-centre compartment despite tripping of the sprinkler system.

However, the cause of the thermal runaway has still not been established. Although the modules present in the storage warehouse have the same technology as those that caused the fire on two buses in Paris in 2023[1], it is hard to extrapolate the cause of the failure insofar as the LMP module does not have the same characteristics in operation and at ambient temperature[2]. The tests conducted show that the module is sensitive to impact and they are inadequate to rule out the possibility of an internal short circuit.

The two root causes of this fire identified at this stage are therefore:

- storage without any particular measures of batteries, some of which had defects, when it is now well known that LMP batteries produce fires of high intensity and rapid kinetics;
- the failure of the manufacturer and owner of these batteries to indicate to the logistics operator the precise nature of the batteries, the associated risks and the appropriate measures to be taken in case of fire.

Several contributing factors were also identified, including:

- the presence of a high-voltage line located about 20 metres from the storage centre, which prevented the deployment of lifting arms by the firefighters. The location of the administrative rooms projecting at the level of the fire walls and the width of the warehouse (100m) were also factors complicating the extinction of the fire;
- the storage of airbags (containing mini-explosive charges) in the same compartment as the batteries could have contributed to the spread of the fire.

1 Rapport du BEA-TT : Rapport d'enquête sur les incendies de deux bus électriques survenus les 4 et 29 avril 2022 à Paris

2 The modules involved in the fire consisted of a solid electrolyte non-conductive at ambient temperature.

FOLLOW-UP ACTION TAKEN

14 inspection visits on site were conducted to manage the follow-up to the fire, and 19 prefectural orders were issued notably to demand remediation of the zone and treatment of the firefighting water, and to require implementation of a pumping system to lower the water table (hydraulic barrier) in order to avoid the dispersal of lithium in the groundwater. The hydraulic barrier and the treatment of firefighting water were time-consuming and costly: 5 months to identify the water treatment method (ion exchange resins) associated with the hydraulic barrier, the operating cost of which was approximately €120,000/month, and 12 months to treat the more than 12,000m^3 of firefighting water collected.

LESSONS LEARNT

Technical lessons drawn from the BEA-RI investigation:

- LMP batteries at end of life require very specific storage conditions, given the heightened risk of thermal runaway and the specific characteristics of the resulting fires (intensity, kinetics, phenomena of molten metal spatter and flows);
- treatment of the lithium present in groundwater is difficult and costly;
- burnt LMP batteries pose even more problems than batteries in sound condition: the waste is water-reactive (outbreak of fire in the presence of water) and releases toxic gases (phosphine). They therefore require specific precautions that only one company in France is currently capable of providing;
- conventional sprinkling can apparently not curb the spread of an LMP battery fire, given the intensity of fires on this type of battery.

Administrative and organisational lessons:

The official operator of the logistics warehouse is a financial company, not technical and not the occupant, which has a number of implications, and in particular:

- the existence of numerous intermediaries (property management, technical management, etc.);
- emergency measures require a major financial commitment that cannot be borne by the financial arrangements of the operator company;
- the impossibility of implicating the de facto operator (occupant of the compartment) under the present regulations.

Moreover, the large number of actors (compartment lessees, the owner of the building, the owner of the land and the owners of the merchandise) also created difficulties:

- impossibility of reaching an agreement between the 12 insurers involved;
- payment problems causing a delay in remediation.

Fire at a used battery storage warehouse

14/02/2024

Viviez (Aveyron)

France

Batteries
Lithium
Warehouse
Fire

THE ACCIDENT AND ITS CONSEQUENCES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On Saturday 17 February, in a warehouse of around 3,000m², a fire broke out on a pallet box containing unpackaged lithium batteries for the consumer market (small batteries for the general public).

In this building, some 1,076 tonnes of lithium batteries were stored on an area of 740m² on behalf of a battery recycling company belonging to the same group (a Seveso Upper Tier establishment located about 500m away). The storage facility contained in particular reconditioned lithium-ion batteries for motor cars and mobile phones, Ni-MH automotive batteries and alkaline/saline base storage batteries.

At 1.54 p.m., a flashing light appeared and the fumes thickened. The fire alarm was triggered at 1.59 p.m. The firefighting and emergency services were called in at 2.18 p.m. after verification by an on-call officer: they arrived on site at 2.33 p.m. The fire had not been brought under control and a large plume of black smoke was released, visible kilometres away. About 60 nearby homes were locked down for 4 hours. Numerous measurements of atmospheric emissions were taken. Spraying, which proved of limited effectiveness, remained in place for 6 days. The extinguishing water was collected in specific basins.

The building was completely destroyed and the facility was shut down. The event had major economic consequences for the facility, but also for the region, still deeply marked more than one year later (short-time working, lost contracts, etc.). On the human and health level, the event caused one slight injury (an employee indisposed by the smoke) and gave rise to 44 reports to healthcare professionals. A health and environmental monitoring plan was implemented to assess the consequences. More than 1,000 measurements were made in surface water, in groundwater, in a swimming pool, in the air, in the fallout of dust, in plants and in honey. A few detections of PM 10 are observed, followed by a return to normal. The decision to stop monitoring was taken in March 2025, i.e. more than one year after the fire.

A volume of about 6,000m³ of hazardous liquid effluents, consisting of firefighting water and rainwater that had come into contact with debris from the fire, was transported to a remote treatment site. The residue of burnt batteries is still on site pending transfer to the adjacent site.


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THE ORIGIN AND THE CAUSES

An analysis of the video surveillance recordings quickly ruled out certain hypotheses concerning the source of the fire, particularly that of a malicious act or a falling storage box. The hypothesis of thermal runaway of a mobile phone battery stored in a pallet box was therefore considered the most likely. The precise cause of the thermal runaway has not yet been able to be determined, although it could have been due to battery damage or wear, or else a short circuit.

FOLLOW-UP ACTION TAKEN

Two days after the start of the event, which was still underway, the prefect convened a post-accident unit, for the first time in the department.

An order instituting emergency measures was published as of the next day to regulate the shutdown of the facility, the continuation of the various measurements in the environment, the establishment of an environmental and health monitoring plan (a system was set up for monitoring healthcare reporting) and management of firefighting water and waste (including the gathering of objects blown away by the battery explosions).

Management of the event entailed 10 meetings of the post-accident unit between 19 February and 18 March 2024, 12 press releases, more than 1,000 analysis results and the collection of 44 reports alerting healthcare professionals.

An investigation was carried out by the BEA-RI (Bureau d'Enquêtes et d'Analyses sur les Risques Industriels, i.e., industrial risk investigation and analysis bureau): in particular, tests were carried out on the conditions of starting of the fire and the extinction strategy adopted.

The shutdown of the facility's activities was partially lifted in July 2024.

Criminal proceedings were also undertaken.

LESSONS LEARNT

Three major points were identified concerning the safety conditions related to:

- the response time: as in most fires, the earlier battery thermal runaway is detected and taken charge of, the greater the chances of limiting spreading of the fire. In particular, the time for verification should be limited insofar as possible, e.g. by using video surveillance;
- the fire extinction resources: the massive use of water is an effective way of limiting the development of a Li-ion battery fire;
- the storage conditions: these play an essential role in the propagation of a thermal runaway: storage in metal drums provides more protection than storage in plastic boxes, by limiting the combustibility of the container and ensuring a form of tightness. The literature also gives grounds for preferring the storage of weakly charged batteries and limiting their period of storage, especially in the case of vehicle batteries for which the state of charge is more easily manageable.

This accident confirms the fact that the regulations on Li-ion batteries must be revised just when an increasing need for recycling of these batteries is emerging. The storage conditions and firefighting facilities should be adapted to the specific features of this equipment.

The toxicity of the fumes remains a recurring issue. The speedy deployment of measuring devices is essential. The use of the on-call laboratory of the adjacent Seveso site (part of the same industrial group) and the deployment of several units of the departmental fire services specialised in chemical hazards were decisive.

Cooperation with state services, under the authority of the Prefect, on complex cross-cutting issues in a crisis situation, cannot be improvised. It must be prepared (post-accident protocol) and tested with drills. The facility operator and the local elected authorities also have an important role to play. Lastly, the proactiveness and transparency of communications regarding the analysis results has enabled to inform the citizens in an enlightened way, albeit with the difficulty of formulating elements of language relating to the eventual toxicity of fumes. The Cartam[1] tool was tested for the first time during this accident.

1 Cartam aims to provide state services and the public, in a centralised and structured manner, with data relating to the pollutant measurements and analyses performed in the environment during a major industrial accident (accident situation) or following it (post-accident situation).

BEA-RI investigations relating to two lithium battery storage fires

BEA-RI INVESTIGATIONS RELATING TO LITHIUM BATTERY FIRES

The BEA-RI (Bureau d'Enquêtes et d'Analyses sur les Risques Industriels, i.e., industrial risk investigation and analysis bureau) was set up in December 2020 to carry out investigations on the most significant accidents coming under Annex 6 of the Seveso Directive which requires a mandatory notification of the Commission, and also following accidents or incidents, even with no casualty or serious damage, that could provide interesting experience feedback. The safety investigations conducted by the BEA-RI should make it possible to determine the circumstances and causes of an accident and to produce, where applicable, recommendations for the operators and the safety authorities. Unlike legal investigations, the safety investigations do not aim to determine any criminal liability.

Against the backdrop of the electrification of uses which entails the increasing use of lithium batteries, the BEA-RI has chosen to investigate accidents related to battery storage or charging which, due to their magnitude or the technical questions they raised, justified opening an investigation. Between 2020 and 2024, 6 investigations[1] were opened for accidents related to these issues.

Two of them concern used battery storage fires that occurred at Grand-Couronne on 16 January 2023 (ARIA 60243) and at Viviez on 14 February 2024 (ARIA 61711).

LITHIUM BATTERY FIRES: TECHNICAL QUESTIONS AND EXPERT APPRAISAL NEEDS

The initial observations made during these two investigations quickly led the BEA-RI to identify technical questions and expert appraisal needs:

- sensitivity of stored modules to thermal runaway in order to understand to what extent a module which is not in operation can go into thermal runaway and produce phenomena corresponding to the descriptions provided by the witnesses;
- kinetics of development of fires involving lithium battery storage facilities in order to learn more about the development and spread of this type of fire, to assess the differences with more "conventional" fires of combustible products and to cross-check the results with the timeline of the emergency services and the damage observed on the buildings and racks;
- influence of storage conditions (plastic boxes or drums) in order to assess the contributions of the packaging method and consider recommendations relating to the practices already noted;
- influence of automatic extinguishing facilities in response to the questions faced in all interventions regarding the possibility of using water or not;
- characterisation of phenomena correlated to the phenomena observed during the fires to try to account for certain peculiar spatter and explosion phenomena reported by the video images and the testimony of the public emergency services;
- assessment of the intensity of the fires so as to have scientific data which will make it possible in future to better assess and characterise battery storage fires according to the type of module;
- adequacy of construction detailing and smoke control systems for fire in a module storage facility in order to understand the propagation mechanisms and, where applicable, re-examine the existing regulations;
- assessment of fire emissions in response to recurring questions in the field regarding the hazardous nature of the fumes.

In response to these questions, the BEA-RI called on INERIS (a recognised public establishment in the field of technological risks) to benefit from its expertise and to perform the necessary tests and analyses for an understanding of the phenomena and to identify safety lessons.

1 Les enquêtes techniques du BEA-RI : Perles et Castelets (2020), Poggio du Nazza (2022), Aghione (2023), Saint-Esprit (2023), Grand-Couronne (2023), Viviez (2024)

TESTS CONDUCTED BY INERIS

The tests conducted by INERIS at the request of the BEA-RI aimed to search for the causes and improve the knowledge of hazardous phenomena related to fires involving lithium batteries.

- Test to search for the possible causes of thermal runaway on stored modules (falls, internal defects). For this purpose, the module was subjected to a compression test (see photo below) which involves crushing it with a ram, and tests to simulate internal defects in the module: a nail test (which involves causing an internal short circuit by passing through the electrochemical cell with a nail) and a localised heating test (which involves applying great heat to the electrochemical cell on a small surface area).
- Tests necessary for an understanding and characterisation of the fire events involving the modules:
    * behaviour of a module exposed to a calibrated flow which consists in submerging the module or box in a fire to see how modules behave when they are caught in a widespread fire;
    * thermal runaway propagation test on a box of modules which consists in igniting one of the modules in the box and observing the propagation of the fire inside the box;
    * thermal runaway propagation test on a stack of storage boxes. This is the same test as before but in a configuration which makes it possible to observe the propagation from box to box.
- Tests necessary for assessment of sprinkling action, which consists in applying an extinguishing system on previously examined storage configurations.

Propagation tests on storage drums

Compression test on modules

LESSONS LEARNT

There are numerous safety lessons.

They aim first to improve the knowledge of fires involving used battery modules. Tests can now provide a large quantity of scientific data to better model the hazardous phenomena related to this type of product: thermal flows, temperatures, duration of the phenomena depending on the battery's chemistry and the nature of the fumes emitted. These data should make it possible to better model module storage fires.

These data also show that with maximum temperatures exceeding 1,600°C in the case of lithium metal modules, the resistance of conventional fire-resistant systems (walls, doors) may be jeopardised, which implies redesigning the module storage conditions by, for example, limiting the quantities stored in the immediate vicinity of such devices.

At the same time, the tests did not show that the use of water on LMP modules on fire would cause an increase in the intensity of the phenomenon. This opens up prospects for the development of firefighting techniques based on the use of water, either for extinguishing systems or with regard to intervention.

As regards the conditions of intervention in the case of fires, the tests show more or less rapid kinetics, which implies the use of early detection systems and automatic extinguishing facilities. If it is chosen to call on teams of first and second responders, it is important that they should have appropriate means of intervention and protection (the extinguisher soon proves insufficient and fire protection clothing is necessary because of possible spatter).

Finally, the tests provide information on the level of danger of the fumes produced by a battery fire (similar to more "conventional" fires) and on the level of danger of the combustion residues of lithium metal modules (the residues are water-reactive, and they produce heat and flammable and toxic gases in contact with water).

The investigation reports[1] describe these aspects in detail.

1 Les enquêtes techniques du BEA-RI : Grand-Couronne (2023), Viviez (2024)

Fire on a container of lithium-ion batteries

06/04/2023

Aghione (Haute-Corse)

France

Battery

Lithium

Stationary energy storage

Fire

THE ACCIDENT AND ITS CONSEQUENCES

At 3.30 p.m. on Thursday 6 April, an outbreak of fire occurred on a photovoltaic power farm on a stationary battery energy storage container. The latter, containing 636 lithium-ion batteries having a total capacity of 4MW, was located in a wooden shed, also containing a transformer (about 1m^3 of mineral oil) and a second battery container alongside.

At 3.31 p.m., the gas extinguishing system of the IG55 type (Argon/Nitrogen) was triggered but failed to stop the fire. The event was rapidly reported to the CODIS (management committee) of Haute-Corse. At 4 p.m., the emergency responders appeared on the site, set up a safety perimeter and made the various emergency power cuts needed to make the site safe, by following the operator's advice over the phone. Fearing that the fire might spread to the second battery container and the transformer, given the impossibility of removing them, the CODIS, after calling on the emergency situation support unit (CASU), decided on massive spraying of the batteries. This operation initially reduced the temperature of the flaming batteries. In the following hours, there were recurring fires until 12 April, requiring regular spraying by the firefighters. The thermal activity stabilised in the following days despite the existence of hot spots identified by thermal imaging camera at the battery level. The firefighters pulled out on 30 April, after 24 days of intervention and monitoring. A single container was affected by the fire; the intervention of the firefighters was able to preserve the second container and the transformer.

When opening the container, a backdraft (overpressure due to the combustion of accumulated flammable gases) combined with a carbon monoxide intoxication led to the evacuation of three slightly injured firefighters. Moreover, due to the shutdown of road D343 over about 200 metres before and after the site access until 11 April, a road diversion had to be organised for the local residents. Although no evacuation of housing was ordered, about ten houses were locked down on the first day because of a potential risk of atmospheric pollution. From the environmental viewpoint, the intervention used more than 15,000m^3 of water to prevent the fire from spreading to the adjacent container. This action limited the extent of the fire and the release of smoke. Although it was not possible to retain the firefighting water on site, subsequent investigations revealed no pollution of the soil or surrounding environment. Lastly, the shutdown of the photovoltaic power farm generated operating losses and caused material damage for the operator, with costs estimated at more than €1 million.

THE ORIGIN AND THE CAUSES

In addition to the legal and insurance appraisals, a BEA-RI investigation was initiated. The BEA-RI report concluded that the fire could have been caused either by an internal defect of a module or by the presence of water inside the container (water produced by the air conditioning system). An examination of the recorded data rather suggests a module defect.

The investigation also identified several contributing factors:

- the ineffectiveness of the inerting extinguishing system: the thermal runaway of modules is more like an exothermic reaction than a fire due mainly to heat. Inerting extinguishing systems which aim to cut off the fire triangle by depriving the fire of oxygen, without any cooling effect, are therefore ineffective on this type of phenomenon;
- the containers were against one another and placed in a masonry building for the purpose of integration into the landscape. This configuration increased the risk of the fire spreading and forced the emergency responders and firefighters to fight the fire with massive quantities of water.

FOLLOW-UP ACTION TAKEN

An order instituting emergency measures was signed on 7 April requiring the implementation of measures to make the facility safe, conducting an environmental diagnosis, dismantling and disposing of damaged modules and prohibiting grazing in the vicinity of the site.

The environmental and health study performed by the operator during the months following the fire did not reveal any significant impact of the event on the surface and deep soils (34 samples), on surface waters (2 samples), on sediments (1 sample) and in plants (5 samples) by comparison with control soil values or regulatory values. However, slight dioxin, furan and heavy metal (zinc, mercury, cadmium) anomalies were detected in the immediate vicinity of the accident. No migration of lithium into the deep soil was identified.

Battery inerting operation

With regard to dismantling of the batteries, which was complex due to the presence of modules that were still charged (65%), the operator commissioned INERIS to establish a protocol in order to ensure and secure the dismantling operations. This intervention protocol defines the means of protection for technicians, the procedures for neutralising the modules in a bath of brine and for their transport with a view to their disposal. Eight technicians trained in interventions on electrical installations and in chemical risks worked in SCBA (self-contained breathing apparatus) for 72 hours to disconnect the batteries and position them in 3% brine baths placed in the open air. Each battery was tracked and its voltage was monitored until complete electrical discharge was reached (0 Volt after about 4 hours' immersion). Each immersion tank was regularly checked for the following factors: temperature of the briny water, surface temperature of the tank, releases of hydrogen (H_2), oxygen (O_2), carbon monoxide (CO), hydrogen sulphide (H_2S) and Volatile Organic Compounds (VOCs). Once it had been electrically discharged, each battery was drained and placed in a box certified 4GV (international carriage of dangerous goods by road - ADR) for shipment to a treatment centre on the continent (Isère region). In all, 4 convoys with about 10 tonnes of batteries were completed by lorry (including transit on boats between Bastia and Marseille).

LESSONS LEARNT

The firefighting strategy employed, notably due to the availability of water in the vicinity of the site, consisted in massively spraying the burnt container with water while protecting the adjacent second container and transformer (about 15,000m3 of water used over the duration of the event given that the fire broke out again many times). While the massive spraying made it possible to prevent widespread thermal runaway and to limit the release of fumes, this intervention strategy nevertheless raises a number of questions.

The BEA-RI investigation report drew a safety lesson with regard to the intervention strategy: given the necessary water resources and the risk of explosion related to opening of the container, an extinguishing intervention should be reserved for situations in which there is a high risk of an aggravating accident by propagation. Otherwise, the choice to "let it burn and control its spread" is probably preferable. Finally, it should be borne in mind that after spraying with water, the dismantling operation is complex because several risks are present: toxic risk due to the presence of hazardous wastes (module combustion residues) and electrical risk due to the presence of modules that are still charged. Furthermore, the BEA-RI report also makes a number of recommendations to the operator and the container manufacturer with regard to:

- the choice of modules: give priority to equipment designed to limit the propagation of thermal runaway (standard UL 9540) or better protected from humidity (high degree of protection);
- extinguishing systems: give priority to systems whose effectiveness has been demonstrated by tests, bearing in mind that water remains the extinguishing agent that can both cool and extinguish;
- the location: install containers in such a way that fire does not spread to an adjacent container or to buildings, so that the strategy of "letting them burn" can be a feasible option. These distances can be reduced if protection systems are planned (e.g., fire-resistive wall). Regarding this, the container location areas must be regularly maintained to prevent the fire from spreading to the vegetation;
- the design of air conditioning systems: special attention must be paid to the design of these systems to deal with the issue of condensation of water, notably by restricting the passage of elements near electrical equipment. Moreover, aircon systems must be monitored and maintained regularly during the life of the container;
- the fire safety plan: it should be produced in conjunction with the public emergency services to define the required water resources.

Release of yellowish fumes during the lithium-ion battery fire

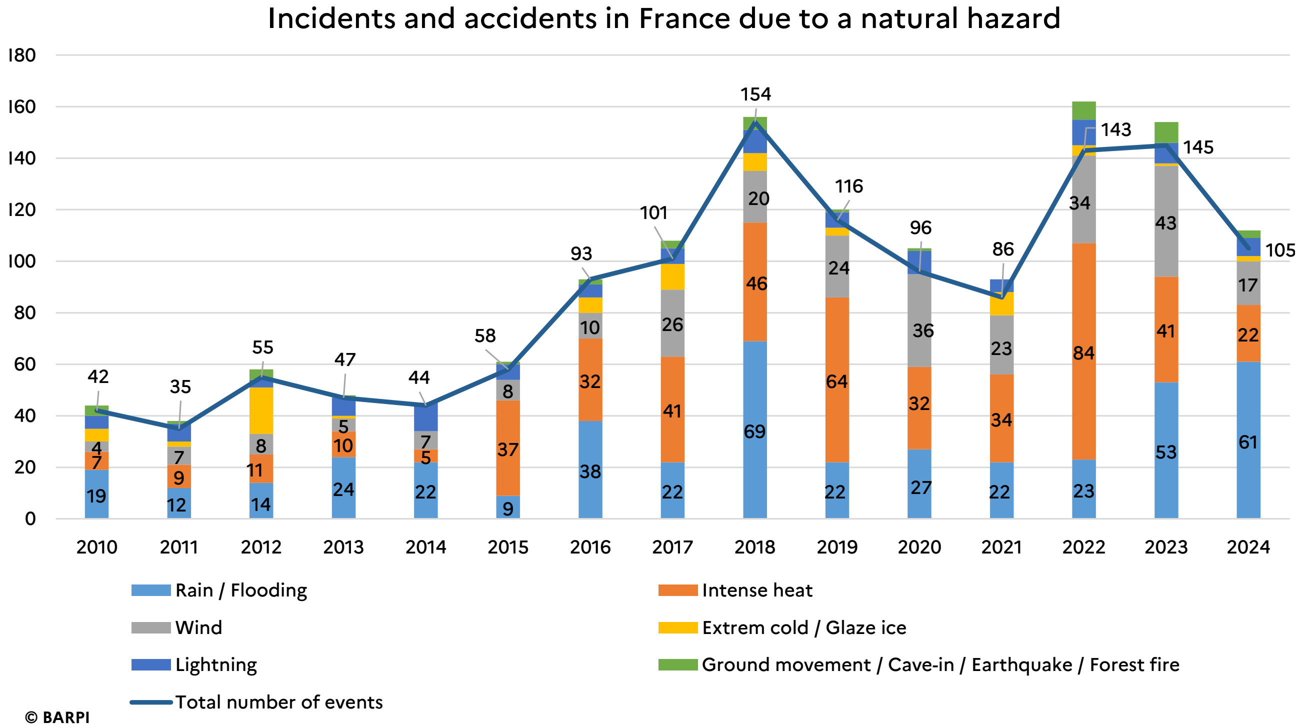
Massive spraying with water

Battery container after fire

NaTech - Focus on floods

The term NaTech is a contraction of "Natural" and "Technological" and represents the impact of natural events on industrial facilities. These natural events mainly comprise climatic events, including heavy rains which can lead to flooding.

1. NaTech in France



This chart shows all the events recorded in the ARIA database regarding facilities of the classified type (whatever the regime) in France between 2010 and 2024[1] due to a natural hazard. The events (incidents or accidents) identified include those for which the natural hazard is the cause of the event, but also those for which it contributed to or exacerbated the event.

Between 2010 and 2018, a significant increase was observed in the incidence rate, followed by a period without any notable tendency, but with major annual variations. This trend is fostered mainly by extreme heat and wind and by rain or flooding; the latter accounted for a total of 437 events out of the 1,320 identified.

2. Events due to flooding

2.1 The relationship with weather conditions

The occurrence of events due to a natural hazard can be correlated, on a macroscopic level, with the weather conditions observed over the same period. This is true in particular for the three years which recorded the largest number of events due to rain/flooding in the ARIA database:

- 2018 was marked by extreme rainfall events in January (with 5 storms and remarkable floods in the northeastern quarter of France) and in autumn (including Mediterranean episodes with intense rainfall and rapidly rising waters);
- 2023, although in line with normal years from the viewpoint of mean rainfall in mainland France, revealed extreme spatio-temporal contrasts, in particular with heavy rainfall in the autumn due to the passage of storms Ciarán and Domingos, which were followed by Storm Elisa;
- 2024 ranks among the 10 years with the most rainfall since 1959. The average 1,075mm of water throughout the country that year was on average 15% above normal everywhere in mainland France (except in the Pyrénées Orientales and Aude departments), with several major rainfall episodes.

This correlation is again found for other meteorological phenomena, as in 2022, a year marked by a sharp increase in events related to intense heat and a record number of days of heatwave.

1 At 1 April 2025

2.2 The nature of the floods

The floods identified in the ARIA database have various sources:

- the direct impact of rainwater (source of most submersions);
- rising waters in a watercourse;
- failure of a dyke or dam;
- rising groundwater.

These various sources can be combined, and zones not reputed floodable sometimes become so.

2.3 Characteristics of the identified events

In the events due to heavy rain and flooding, the hazardous phenomenon mostly encountered is the release of hazardous or polluting substances. No fatal accident was identified in France in the ARIA database over the period studied (2010-2024). There were major social repercussions due to temporary layoffs. The environmental consequences are generally related to impacts on waters or soils. Lastly, major economic consequences are often recorded, due to material damage and internal operating losses.

During events related to rain/flooding, problems of intervention are often encountered, regarding:

- access to the site (water height, etc.);
- the need to create a remote control centre;
- electrical utility outage;
- the significant pumping capacity to be deployed;
- the lack of specific intervention resources (diving suits, dinghies, forklift trucks, etc.).;
- difficult weather conditions making it impossible, at times, to use aerial resources;
- the scale of the geographic area impacted, with civil protection resources employed in priority to provide assistance to the populations.

2.4 Experience feedback based on events related to rain and flooding

The following lessons can be learnt from analysing the events listed in the ARIA database. The measures to be taken are, in particular:

- identify the risk of flooding on the site by determining a zoning map but also a potential intensity of the climate hazard;
- anticipate the difficulties that could be encountered: the impact of water on the site, the loss of utilities and means of communication, accessibility of the site, the presence of objects that could cause debris jams, the seepage of surface water and water rising up via the utilities, the risk of malfunctioning of accessory process systems, such as the fire safety system), etc.;
- implement mitigation measures appropriate to the vulnerability of the facilities and the kinetics of the event, involving one of the following strategies: resist by preventing water from entering the site or manage the onrush of water by taking the necessary measures to limit the damage and reduce the time needed for a return to "normal". Work is required for forward planning of the capacity of human resources to go to the site and identify the necessary intervention equipment. Staff training and awareness raising in flood-risk management is essential, moreover, and this risk should also be included in a facility's specific procedures. Finally, monitoring weather warnings, particularly with warning maps that give 24-hour warnings of approaching weather hazards (https://vigilance.meteofrance.fr), and flood warning maps (https://www.vigicrues.gouv.fr/) make it possible to prepare beforehand the protective measures to be implemented on the site.

ARIA 50402 – 31/08/2017 – Crosby – United States of America

Several fires and explosions occurred at a chemical plant manufacturing organic peroxides.

136 tonnes of organic peroxides burned. An evacuation zone of 2.4km radius, covering 205 residents, was established. 21 people consulted with a medical service due to the inhalation of fumes.

One week earlier, following the announcement of a pending hurricane, the operator had taken the measures it considered necessary and adapted them in line with changes in the weather conditions. However, the passage of the hurricane caused flooding of the plant due to a higher-than-expected rise in water levels, causing the loss of the permanent generators, emergency generators, a liquid nitrogen cooling system and the vehicles on the site. Although all the containers of organic peroxides (unstable compounds which decompose rapidly, releasing a large quantity of heat at ambient temperature) were moved into trailers located on the highest part of the site (including 2,000 containers moved manually), their cooling was no longer ensured. Three containers caught fire. The operator set off controlled fires in the other 6 containers. The flood incurred was that of a 100- to 500-year return period and resulted in up to 1.8m of water in the plant. The operator had based its flood plan on its employees' memory of a flood of at most 60 cm of water.

Managing risks from natural hazards to hazardous installations (NaTech) : a guide for senior leaders in industry and public authorities

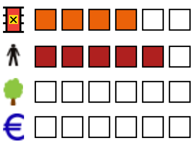
Natural hazards such as lightning, high and low temperatures, landslides, earthquakes or floods can impact the operation and safety of hazardous installations and result in accidents referred to as Natural Hazard Triggered Technological accidents, or NaTech accidents. Installations that process, store or handle hazardous substances can in principle be vulnerable to the impact of natural hazards. Leaders in industry and public authorities play an important role to ensure the appropriate governance and management of NaTech risk. Leadership, combined with appropriate technical assessment, will enable long-term operability and sustainable development at hazardous installations, including those whose threat level increases due to climate change. This guidance is geared to support senior leaders in industry and public authorities implement NaTech prevention, preparedness and response measures.

The guidance has been jointly developed by the Organisation for Economic Cooperation and Development (OECD), the Joint Research Centre of the European Commission (JRC) and the United Nations Economic Commission for Europe (UNECE).

1. The case for NaTech risk management

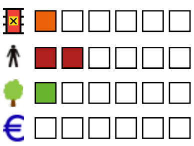
The case for NaTech risk management is strong for both businesses and public authorities. Failure to address the potential impacts from natural hazards can lead to significant costs, damage to people and the natural and built environment, injury, business interruption, loss of reputation and ultimately to the failure of the company.

Recent NaTech accidents around the globe have caused major damage to hazardous installations with often disastrous effects on human lives, the environment, infrastructure, regional security and economic development. The guidance takes as examples the lightning strike that hit an oil storage terminal in Cuba in August 2022 and the massive rainfall from Hurricane Harvey that led to the flooding of a chemical plant handling organic peroxides in the United States in August 2017.



ARIA 59453 – 05/08/2022 – Matanzas – Cuba

In August 2022, a lightning strike hit an oil storage terminal in Cuba, triggering a major fire and explosions that eventually involved four large storage tanks. Seventeen fire fighters lost their lives in the attempt to keep the fire from escalating and avoid a domino effect. International aid was needed to control the fire.



ARIA 50402 – 31/08/2017 – Crosby – United States of America

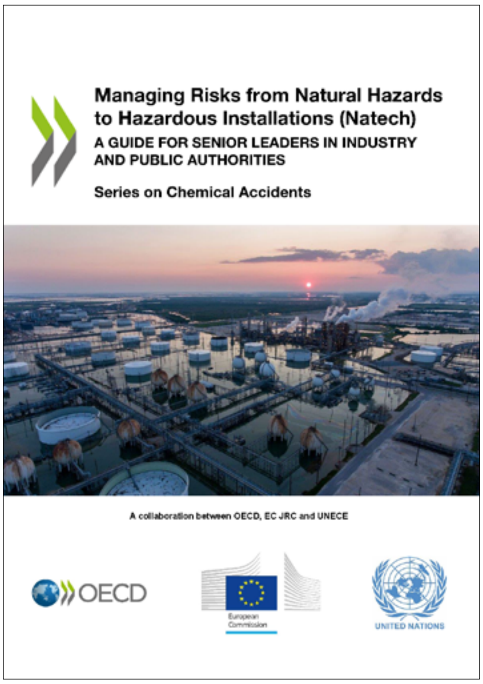
In August 2017, massive rainfall from Hurricane Harvey led to the flooding of a chemical plant handling organic peroxides in the USA. The flood triggered a blackout, resulting in the loss of all refrigeration systems onsite. The organic peroxides decomposed and combusted, exposing first responders to the toxic fumes and necessitating evacuation over a 1.5 mile radius.

The guidance aims to challenge senior leaders in industry and public authorities to consider questions such as:

- what should I do to ensure good governance of NaTech risk?
- how do I gather and organise the capabilities and competences to do it?
- how do I ensure that my organisation continues to adapt to a changing environment?

This document will aid senior leaders to be able to self-assess how prepared their organisation is in managing NaTech risks effectively.

2. Topics covered by the guidance



The guidance covers the main elements that senior leaders should consider to ensure efficient NaTech risk management. It provides targeted guidance to leaders in industry and to leaders in public authorities and highlights when cooperation between industry and public authorities is necessary. The topics covered include:

1. Risk Awareness and Governance: Understanding Vulnerabilities and Risks

- Risk awareness at all levels, led from the top
- List critical elements for leaders in industry and public authorities to ensure consideration of NaTech risks within their organisation

2. Preventing NaTech Accidents

- Identification of the natural hazards that may affect an installation
- Assessment of the risks posed by natural hazards to industrial sites
- Consideration of natural hazards, and the impact of climate change, in design, construction, modification, siting and operation, and in land use planning and permitting
- Learning from past accidents

3. Emergency Preparedness and Response

- Ensure that emergency plans off-site and on-site are in place and working
- Ensure that early warning systems and alert systems are in place and functional

4. Communication of NaTech Risks and in Case of Natech Accidents

Key measures to ensure communication:

- With employees at hazardous installations
- Between industry and public authorities
- With the public and communities

The guidance also provides self-assessment checklists to help senior leaders in industry evaluate how well they are including Natech risk as part of their organisation's process safety management; and help senior leaders in public authorities to ensure that the impact of natural hazards on hazardous installations is fully considered in the safety strategy and inspection and enforcement measures. The checklists include a list of questions using 'traffic light' scores (the image below is part of the checklist for industry).

SELF-ASSESSMENT CHECKLIST FOR SENIOR LEADERS IN INDUSTRY

Preventing Natech Accidents			
1. Are you aware of the natural hazards that can impact your installations, wherever they are located in the world?			
• Do you know the type of natural hazards that can have an impact?			
• Do you know what type of impacts these natural hazards can have on your installation(s)?			
• Do you know how climate change projections may alter these natural hazard intensities and frequencies?			
• Are you proactively searching for this information?			
2. Do you know the main challenges of Natech risk?			
3. Have you ensured that Natech risk management is integrated into your chemical accidents prevention, preparedness and response measures?			
4. Have you ensured that Natech risk management identifies all relevant Natech scenarios, including those triggered by "minor" natural hazards, such as lightning and low temperatures?			
5. Have you ensured that sufficient human, financial and time resources are available to fully include Natech risk management as part of process safety procedures within your organisation?			

Feedback on the storms in France

November 2023

France

Natural hazards
Floods
Wind
Safety measures

THE METEOROLOGICAL SITUATION

At the start of November 2023, mainland France was hit by two violent storms, Ciarán and Domingos, followed by Storm Elisa. From 1 November, there were strong gusts of wind and numerous new wind speed records were established. Heavy rain fell from 3 November, and particularly from 5 November in north-western Pas-de-Calais. This rainy spell, which lasted until 10 November, caused exceptional rises in the water on certain watercourses, in particular the LIANE, the CANCHE and the AA. There was a lull on 11 and 12 November before the rain resumed on 13 November.

THE CONSEQUENCES FOR INDUSTRIAL FACILITIES SUBJECT TO PERMIT

27 events concerning classified facilities for environmental protection subject to permit, resulting from the storms which affected mainland France in early November 2023, were recorded in the ARIA database. This sample is not an exhaustive list of all the events occurring during the period in relation to the aforementioned meteorological conditions, but shows an accident trend. The storms hit northwestern mainland France in particular, and the incidence rate reflects this. The regions most affected were the Hauts-de-France region and Brittany.

More than half of the sites affected were sites coming under the Seveso directive, with 7 sites classified as Seveso upper tier and 7 sites classified as Seveso lower tier.

16 events concerned manufacturing industry.

No death or injury was detected. Six events were classified as accidents, notably due to the economic consequences and temporary layoffs.

No major dangerous phenomenon (fire, explosion or release of hazardous or polluting substances) was observed in the 27 events examined. An estimated 960m^3 biogas release was detected upon tearing of the membrane of a compartment at a non-hazardous waste storage facility (ARIA 61156), as well as a release of hydrochloric acid vapours (without any product loss) after the manhole was ripped off a tank (ARIA 61233). Eight cases of harm to the physical integrity of equipment (excluding capacity) were identified (ARIA 61127, 61131, 61151, 61166, 61167, 61169, 61466, 61469). The failure of an alarm, due to the loss of the electrical utility, meant that of the operator of a poultry farm received no information about the outage of its ventilation system, causing the death of 40,000 chickens (ARIA 61170). One event, moreover, was due to the fact that a railway line was impassable for a period of several weeks, making it impossible to send the production of hazardous substances from the plant by rail (ARIA 61231). The manufacturing process of this plant is continuous and cannot be interrupted without damaging the production tool. The limitations on shipment of hazardous substances led the plant temporarily to have a volume in storage exceeding what was planned in normal operating conditions.

ARIA 61163 – 06/11/2023 – Blendecques (Pas-de-Calais) – France

Following heavy rain in the wake of storms Ciarán and Domingos, the operator of a paper mill noted that the AA River running along its site had left its bed. Bales of paper were put in place to try to check water ingress on the site. At 1.15 p.m., the municipal police gave the order to evacuate the site. At 9 p.m., water reached the maintenance and shipment area, and the site could no longer be accessed on foot. Two days later, the water withdrew from the site. Pumping operations were organised, and the personnel returned to the site. Storm Elisa, which followed 3 days later, caused a second round of flooding. The staff were evacuated. A surveillance team remained on the site. Only the boiler, the wastewater treatment plant and the transformers remained in operation. The site was flooded in the afternoon and there were large debris jams caused by wood waste. Access to the inside of the establishment was no longer possible the next day. The electric power supply and the boiler gas intake were cut off. The water gradually withdrew from the building, 6 days after the start of the event. The WWTP was stopped due to the lack of electricity. 10 days after the first round of flooding, all the personnel returned to the site. The plant was repaired and the machines were gradually restarted. The WWTP was reseeded 6 days later, because the 2-day stoppage due to the power failure had caused the loss of bacteria.

The plant was shut down completely for five days, and the personnel could not obtain access to it. 143 employees (excluding temporary workers) were placed on short-time work.

No equipment or product was carried away by the floods. The hazardous substance storage facilities had been raised above the ground. The operator estimated the cost due to the floods at €2.5m, including losses of finished product stocks, production losses and cancelled orders, and damage to the buildings and machines.

Note that 6 days after the start of the event, a fall in the Aa's water level was indicated at the end of the morning on the website containing information on the risk of rising watercourse waters, but the water level on the site was still high in the afternoon. Regarding the gas cutoff, only the gas before the boiler had been shut off; the main shutoff valve had not been able to be activated, because it was inaccessible. The operator indicated that 10% of its personnel were also severely impacted by the floods affecting their property and personal life.

The plant had suffered a major fire 20 months earlier (ARIA 58834).

Other businesses were impacted in the same geographic area.

THE ORIGIN AND THE CAUSES

Apart from direct harm to the facilities by fierce storms, other disruptions caused the events within the scope of the study:

- losses of electrical utility were recorded in 8 events, i.e. more than one-quarter of the events identified (ARIA 61128, 61129, 61131, 61151, 61156, 61170, 61466, 61469). Some of them were prolonged, lasting several days. To counter part of their effects, human presence was stepped up particularly on certain industrial sites, with, for example, the establishment of extra patrols;
- equipment faults in 7 events (ARIA 61128, 61156, 61169, 61170, 61231, 61233, 61466). These included the event in which the manhole of a tank was ripped off by the violent winds of Storm Domingos due to corroded fasteners (ARIA 61233);
- latent hazards[1] in 4 events (ARIA 61127, 61131, 61147, 61231). These included problems of communication due to widespread malfunctioning of telephone networks (ARIA 61131);
- a human action not performed following an electric power failure which caused actuation of the automatic extinguishing system. The guard, despite being present on site, was unable to stop the automatic extinguishing system, because the weather conditions did not enable him to obtain access to the room in question (ARIA 61131).

LESSONS LEARNT

By analysing the 27 events recorded in the ARIA database related to this spell of storms, the following lessons can be learnt:

- a classification of the meteorological phenomena encountered:
  * the wind, with recorded speeds higher than those customarily observed;
  * rain and flooding, with repeated floods in the areas impacted and rising waters recurring at industrial facilities;
- a major geographic impact of meteorological phenomena:
  * a broad geographic area was affected, with significant consequences for civil society, calling heavily on public emergency responders, the services in charge of electricity and telephone transmission and distribution systems, and the services in charge of maintaining communication channels (road and rail). These services were extremely busy over a limited period of time. They were hard to reach and often had no precise information regarding progress on clean-up and repair work. The emergency services acted in priority to help the population and could not, at least initially, deploy their resources to help the operators, who had to manage the degraded situation they faced with their own resources;
  * large-scale losses of electrical utilities with the return to normal taking far longer than during power cuts caused by an isolated fault;
  * communication problems due to the outage of fixed and mobile telephone services (loss of certain antennas) and communication channels (road or rail) cut off.

To find out more

1 Latent hazard: within the meaning of the BARPI terminology, a latent hazard is an underlying threat to safety. It requires a triggering factor in order to materialise in the form of a hazardous phenomenon.

Consequences of flooding on industrial sites

May 2023

Ravenna (Emilia-Romagna)

Italy

Natural hazard
Lightning
Floods

The Emilia Romagna region is characterized by hazard scenarios equal to P3[1], with return times of 20-50 years, and P2 with return times of 100-200 years. Two sequential events occurred in less than twenty days, with cumulative monthly rainfall exceeding 450 mm in different locations. From 15th to 17th May 2023, rain peaks of 300 mm on the ridge basins and Forlì hill occurred. In the same area, on the hills and mountains of Ravenna and on the eastern sector of Bologna, between 150 and 200 mm fell. On the Cesena Forlì lowland area, rain peaks up to 150 mm fell. These two extreme rain events happened in the same area just two weeks apart, in the same river basins. The floods were concentrated in the Bologna, Forlì-Cesena and Ravenna areas, strongly affected in terms of meteorological-hydrogeological-hydraulic alerts, river flooding and consequent landslides and flooding, and consequences on artisanal and industrial plants. Three cases occurring in the province of Ravenna have been analyzed: two flooding events which put in evidence how the safety management system and the emergency procedure improvements have led the critical issues to be managed, and one industrial accident, occurring between 2 flooding events, where the important local emergency action led to contain spills of fire water into the environment.

CASE 1 - ARIA 64250: ORIGIN, CAUSES AND CONSEQUENCES

The Ravenna Industrial Park is located between the 2 protected natural areas of Piallassa Baiona and Piallassa Piomboni, a few kilometers from the city of Ravenna, alongside the navigable CANDIANO canal, which connects the site to the sea and is used for the raw materials and finished products transfer. The Ravenna industrial site consists of 9 Seveso plants inside, and 5 Seveso plants outside the site boundary. In February 2015, an initial flood event occurred from the CANDIANO canal for the petrochemical site following adverse weather conditions, high tide on the canal, strong Bora wind and rain. The event resulted in the breakage of the CANDIANO embankment (construction work in progress outside the site), the rapid rise in water level in sewer pipes, and in some areas of Seveso fertilizer production plant (including the reaction building, the grinding building, the materials warehouse, and the fertilizer warehouses being affected). All the supplying utilities plants on the multi-company site went into emergency. Following this event, the safety management system procedures were prepared for the management of flood events: site emergency procedure and site procedure for flooding from the CANDIANO Canal, essential for managing the 2023 flood risk.

On the 16th and 17th of May the flooding of the rivers, the breaching of the banks of the SILLARO, SANTERNO, SENIO, LAMONE, and SAVIO rivers, and the compromise of the secondary water system (canals) with the overflow of the network of consortium canals (Romagna and Western Romagna and Emiliano-Romagnolo Canal) led to a high industrial risk. Specifically, the floodwater from the VIA CUPA canal could flow into the supply channel that feeds the plants of the Ravenna industrial site for all uses (system cooling, fire suppression, process water, etc.) and compromise the facilities due to the high turbidity, as well as flood the entire industrial site.

The Ravenna industrial site has implemented the site emergency procedure for the management of a possible ground flood (canal) and the site procedure for the management of flooding from the CANDIANO canal to prevent the entry of water from the sea. Emergency Committee set up with all the facilities directors : positioning of benches to protect the passages where the walls of the CANDIANO canal are interrupted, planning and securing of the systems, preparation of the stop ladder, suspension of the production, positioning of sandbags to protect the plants and along the embankment and near the canal.

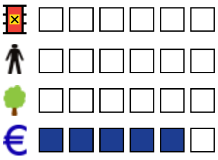
Meanwhile, following the initial weather alert, an Emergency Coordination Center (CCS) was immediately established at the Ravenna Prefecture in response to the worsening weather conditions. The Prefect directed all RIR companies to implement all the necessary safety measures to prevent the release of hazardous substances in the event of flooding. Continuous communication was maintained between the Prefect and the safety committee of the industrial site. Finally, an order was issued for the forced breaching of the VIA CUPA canal embankment to prevent flooding of both the industrial site and the city of Ravenna. Assistance was requested from the EU Civil Protection Mechanism. Earth embankments were positioned to protect the city.

The Emilia-Romagna Region website[2] is highly relevant. It was created to unify information and data for risk management, support the actions of civil protection authorities, and inform the population in real-time (attention, pre-alarm, alarm (e.g., river floods, landslides and flash floods, sea state, wind).

1 The Directive 2007/60/EC and the Legislative Decree 49/2010 provide for three flood scenarios relating to natural watercourses (RP - Main Network and RSCM - Hilly Mountain Secondary Network areas): Scenario of high probability of flooding (P3), Scenario of medium probability of flooding (P2), Scenario of low probability of flooding or Scenarios of extreme events (P1).

2 Managed by the Hydro-Meteo-Climate Service of the Regional Agency for Prevention, Environment and Energy (ARPAE) together with the regional Civil Protection

CASE 2 - ARIA 64252: ORIGIN, CAUSES AND CONSEQUENCES

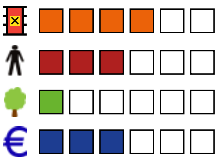


A biogas plant located in a food processing and renewable energy production company in Conselice (Ravenna), is situated in an area of high hydraulic risk. This area is positioned between the SILLARO, SANTERNO, and RENO rivers and crossed by some of the main canals of the drainage system. The area, with a very high risk of flooding, has a particularly low altitude and is geographically depressed: the plant is located in a depression created by centuries of land reclamation where all the waters that could potentially overflow from the SILLARO and SANTERNO rivers, particularly on their respective right and left banks, tend to converge. The site was flooded on the 16th and 17th of May 2023, under 2 to 2.5 meters of water for 3 weeks. All electrical power supply systems, both internal - cogeneration - and external - AT Terna and MT Enel - were irreparably damaged, leaving people without electricity until October-November. Three specialized disaster recovery companies worked on-site with approximately 600 personnel until after the summer. The direct damages caused by the accident exceed 100 million euros. The CCS, operating at the Ravenna Prefecture, managed the flood event that affected the company in Conselice. Malfunctions in the drainage system (under extreme stress), particularly at the Sabbadina pumping station, where the company's discharge is also located, required the intervention of public authorities and EU Civil Protection, with more effective pumps. The dynamics of the flooding, in which the water rose slowly and receded even more slowly, ensured that materials remained within the production departments and storage areas. The tanks, nearly full and securely anchored to the ground, did not float. No industrial waste contamination was detected.

Water monitoring samples were collected by the environmental prevention agency near the tank farm, the tanker truck area, and the refinery's loading bay to test for total hydrocarbons, oils and fats in the ditches, and Escherichia coli. The analysis results indicated no signs of industrial pollution. Only BOD5 and phosphorus were slightly higher than the reference thresholds. Regarding the canals near the company, the very serious problem concerned the high organic load and total anoxia of the waters, which caused the death of the fish. The high organic load was attributed to the presence of civil sewage following the rupture of the Conselice city sewer. Furthermore, during the company's recovery activities, approximately 9,000 tons of waste (solid and liquid) were generated.

An extraordinary vaccination campaign was carried out by the Romagna Health Authority (Ravenna), aimed at preventive health actions. It received great participation among the population, especially in the areas most affected by the flood. In the first few days, over 3,000 vaccines (tetanus) were administered, and in Conselice, the area most affected by the presence of still undrained waters, vaccinations involved over 700 citizens (tetanus and hepatitis A vaccination), a significant number for a town of 9,000 inhabitants.

CASE 3 - ARIA 64251: ORIGIN, CAUSES AND CONSEQUENCES



A fire occurred in the storage of ethyl alcohol at a Seveso plant (upper tier) in Faenza (Ravenna), which main activity is the processing of products and by-products of winemaking. The event (fire with subsequent explosion) originated in a warehouse, with 30 tanks of 200 m³ each of ethyl alcohol. In the day of the event, a third-party company was on site to complete the extraordinary maintenance work started in the previous week, on the group of 6 tanks, empty and reclaimed. The work involved welding, and since the area was ATEX classified, the third-party company had prepared the work area by adopting some safety precautions. Other activities were underway in the warehouse area. A first explosion occurred around 11.44 am on 8th May, followed by 2 further explosions with flames, approximately 10 s apart. The Internal Emergency Plan (PEI) was immediately activated, with the total evacuation of the plant. All employees, present inside the plant (internal, contractors, drivers), went to the assemply point. The Fire Brigade, promptly called, arrived immediately thanks to an active point in the municipality of Faenza, close to the plant, due to the flood of the previous week. Consequently, the Prefect, having consulted the technical bodies (Fire Brigade and ARPAE), ordered the activation of the External Emergency Plan. The event occurred between 2 important flood phenomena that hit the Faenza area hard in May 2023: the first, which occurred a few days before the event, despite its negativity, in a certain sense 'favored' the emergency response of the Fire Brigade who was, at the time of the accident, in the neighboring area for post-flood management. The second, following the event, complicated the management of the purifier, resulting in the increase in pollutants in the waste water. Precautionarily adopted in the Emergency Center, between the first and second flood, when the accidental event occurred in the presence of heavy rain, an earth damming action was initiated in the consortium canals to contain spills of fire water into the environment, then collected by drain trucks.

LESSONS LEARNT

CASE 1 - ARIA 64250

Strengths:

- Activation of the CCS during the weather warning phase;
- Proper and effective exchange of information with a WhatsApp group for CCS members and forces in the field;
- Website to unify information, support the actions of civil protection authorities, and inform the population in real-time;
- Immediate establishment of specific tables as needed: at the Prefecture, the prompt establishment of dedicated working groups according to urgent issues, such as environmental risk and land management;
- Very close collaboration between differents actors (Companies, Institutions, Authorities);
- Strong collaboration between the Regional Civil Protection Agency, the EU Civil Protection, and the reclamation consortia (Western Romagna, Romagna, Emiliano Romagnolo Canal) for the management of rivers and canals, and the Site Emergency Committee for the management of the industrial site.

New measures adopted: a new hydraulic connection channel is under construction to divert water during adverse weather events (on a plot of agricultural land that, during the May 2023 flood, was inundated by water diverted there following the artificial breaching of the ditch's bank to save the petrochemical site and the city of Ravenna from flooding).

CASE 2 - ARIA 64252

Malfunctions in the drainage system (under extreme stress), particularly at the Sabbadina pumping station, required the intervention of public authorities and EU Civil Protection with more effective pumps. Numerous samples and analyses were carried out for environmental monitoring to determine the potential level of pollution.

Some critical elements:

- Critical issues review (in terms of design and working) linked to the Natech accident risk (pumps, tanks, electrical devices, ...);
- New rules defining a specific person following the weather forecast, a person managing the alarms in the plant, a person verifying the situation after the natural event (checking if the systems and devices work well and are reliable);
- Requirement to implement additional containment measures.

Strengths: very close collaboration and synergy between Companies – Institutions – Authorities.

New measures adopted: setting up a custom-designed flood protection system around the site consisting of a barrier constructed from steel sheet piles and earth embankments (with 3 hydraulically operated sliding gates designed to withstand the anticipated flood loads and closed during weather alerts).

CASE 3 - ARIA 64251

Some critical elements, waiting for the legal investigation conclusions:

- Open cycle ethyl alcohol transfer: due to the high flammability of the substance (ethanol), it is better to adopt a closed cycle transfer. In case of an open cycle transfer, it needs to have adequate ventilation that avoids the creation of a flammable mixture;
- Activation of flammable gas detectors in the warehouse: the flammable gas detectors did not work. There are doubts about the number and distribution of detectors present and their ability to promptly signal the presence of flammable vapours;
- Activation of the cooling system of the nearby storage: fire fighters reported the difficulty in activating the cooling system of the tanks in the nearby area (mostly containing pure ethyl alcohol or in solution) due to the strong radiation produced by the fire. There is a need to adopt a different activation system of the sprinkler system for the protection of storages (automatic or, if manual, at least remotely activated in a protected position).

Flooding of a Seveso plastics manufacturing plant

17/05/2024

Sarralbe (Moselle)

France

Flooding
Losses of utilities
Pollution
Seveso

THE ACCIDENT AND ITS CONSEQUENCES

Context

Between 16 and 19 May 2024, exceptional weather conditions in terms of rainfall affected the city of Sarralbe and its surrounds. On yellow alert as of 4 p.m. on 16 May and then orange alert ("rain and flooding") from 10 a.m. on 17 May, the equivalent of more than one month of rain fell in Moselle in less than 2 days (76.3mm in 36 hours in the Sarralbe district – source: French met office Météo France). This exceptional phenomenon combined with a high humidity level in the ground (as a result of heavy rainfall between October 2023 and April 2024) caused the (WILLERLACHGRABEN and SARRE) watercourses to rise suddenly and rapidly and then overflow, but also created substantial surface runoff. The city of Sarralbe was particularly affected by these floods, and 150 inhabitants had to evacuate. The state recognised the district as a natural disaster area following this event.

Flooded county road

Chronology and consequences

The plant in question is specialised in plastics manufacturing. It is split into 2 parts, "East" and "West". Each part of the plant was impacted by different phenomena: the "East" part by the overflow of the SARRE and the "West" part by the rise and overflow of the waters of the pond used as a firefighting water reserve and by surface runoff phenomena on the site.

- at 10 a.m. on 17 May 2024, the plant went into alert mode and set up a crisis management unit to manage the situation and identify the various areas affected by flooding;
- at 3 p.m., due to the worsening actual water levels and weather forecasts, the polymerisation lines were all placed in dilution, to prepare for a safe shutdown;
- although outside the PPRi[1] zone, the pond which serves as a firefighting water reserve (fed by a stream and by runoff water from the surrounding areas) rose to a very high level, overflowed onto the road and flooded the fire hose station. At 4.40 p.m., the operator therefore decided to isolate the electric pumps and start the diesel pumps to ensure the availability of the fire protection system. This event had not been taken into account in the hazard analysis and in the internal emergency plan, since the "West" zone had not been identified in the PPRi;
- at the same time, the heavy rainfall abundantly filled the outlet basin receiving rainwater from the plant by runoff (delivery of approximately 800m^3/h instead of 30m^3/h in normal operation). This basin was used to collect the industrial plastic pellets (IPPs) not held back by the upstream prevention systems. The operator opened the valves located at mid-depth of this basin at around 11 a.m. to prevent it from overflowing and to minimise the impact of floating IPPs on the environment. However, eddies in the outlet basin, due to the strong incoming flow, caused stirring of the IPPs and their release into the WILLERLACHGRABEN, located downstream of this basin;
- the runoff waters also significantly filled the buffer tank present in the "West" zone, which collected industrial effluents, and the zones on a retention system. To prevent this basin from overflowing and saturating the final industrial effluent treatment station located in the "East" zone, the operator diverted the effluents from the buffer tank to the rainwater outlet basin for several hours;
- at 3 a.m. on 18 May 2024, the water level fell in the fire hose station. The crisis management unit was closed because the situation was under control;
- at 9 a.m., an in-house firefighter intervened on site to close the outlet basin valves again. He detected damage resulting from the flooding and in particular the overflow of IPPs onto the banks of the WILLERLACHGRABEN;
- at 6.30 p.m., it was decided to restart the polymerisation lines.

Apart from the economic aspect of the damage and the shutdown of the production lines (approx. €320k), the main consequence of this event was environmental, because a mixture of rainwater and wastewater containing plastic particles (polyethylene and propylene) was discharged into the stream (WILLERLACHGRABEN) downstream of the plant. This pollution was taken care of by the operator immediately after the accident.

1 PPRi: Plan de Prévention du Risque Inondation (Flood Risk Prevention Plan)

THE ORIGIN AND THE CAUSES

The high level of humidity in the ground (> 77% on 16 May 2024) due to heavy rainfall between October 2023 and April 2024 and the stationary rainy spell between 16 and 19 May 2024 caused the floods in the city of Sarralbe.

The lack of procedure and consideration of the risk of flooding for the "West" part of the plant in the internal emergency plan and in the flood risk prevention plan could have been the cause of a loss of "firefighting" utility on the site. However, the operator set up a control centre (PCex) from the outset of the crisis in order to implement measures to ensure safety and in particular to maintain the plant's fire safety.

The presence of industrial plastic pellets (IPPs) in the outlet basin and the diversion of part of the industrial effluents coming from the buffer tank to the outlet basin impacted the watercourse (WILLERLACHGRABEN) located downstream of the rainwater discharge from the "West" zone.

FOLLOW-UP ACTION TAKEN

The following measures were taken during the event:

- electrical isolation of the electric pumps of the fire hose station and activation of the diesel pumps in order to maintain fire safety on site. Check on the level of the diesel tank for reordering if necessary;
- notice given to the police department concerning the road risk after flooding of the trunk road between Sarralbe and Willerwald;
- opening of the outlet basin valves to prevent them from overflowing and consequently releasing floating elements;
- diverting water from the buffer tank to the outlet basin to avoid saturating the plant's industrial water treatment plant ("East" part);
- cleaning of the environment (banks of the WILLERLACHGRABEN) after the release of plastic particles.

Note that the equipment of the fire hose station was raised above the ground and this made it possible, on the day of the flood, to gain time on the rising waters of the pond in order to define a strategy for maintaining the plant's fire safety.

The following measures were taken after the event:

Updating of the internal emergency plan to take into account the risk of flooding in the "West" zone of the plant. This update indicated the measures to be taken in the event of a rise in the level of the pond, and in particular:

- stoppage of the electric pumps;
- placing the production lines in dilution;
- monitoring of the water level in the fire hose station to consider starting the diesel pumps before the water level submerges the starter battery;
- monitoring of fuel consumption for diesel engines.

LESSONS LEARNT

1 – Adaptation to large-scale floods partly due to surface runoff

Floods are generally associated with a risk identified in zoning in the Flood Risk Prevention Plan or geographic proximity with a watercourse. However, the flood which affected Sarralbe in May 2024 was far more complex, because the surrounding watercourses overflowed as a result of rising waters and the runoff phenomenon added to the disaster, causing flooding in zones not identified in the zoning map. According to the Flood Risk Prevention Plan, only the "East" zone of the plant was concerned by a risk of flooding. It was therefore difficult for the industrial firm to identify this risk on this zone and to implement measures.

The flooding of 17 May 2024 highlighted the importance of adapting crisis management protocols to identify and include scenarios of intense surface runoff in particular. The recommended measures included:

- the establishment of level monitoring systems for the water reserves and basins of industrial plants;
- the revision and extension of emergency plans to manage this type of flooding;
- staff training in the new emergency protocols.

2 – Positioning of fire hose stations near firefighting water reserves liable to undergo flooding

It is not uncommon, on industrial sites, for the fire hose station to be located near (artificial or natural) water reserves. Hence, in light of the event of 17 May 2024, the risk of flooding of the fire protection room should be considered by industrial firms having a similar configuration. This event underlines the need to protect critical infrastructure. The measures to be taken could include:

- raising pumps and auxiliary equipment (electrical cabinets, etc.) above the ground to prevent them from being submerged;
- improvement of drainage systems around sensitive installations;
- regular maintenance and readiness of standby diesel pumps to ensure the continuity of fire protection;
- establishment of alert thresholds based on the water level and definition of the measures to be taken for each threshold.

FACT SHEET

Loss of electrical utilities
Ensure the operation of backup electrical installations

The ARIA database inventories more than 200 events caused by the loss of electrical utilities, affecting all sectors of activity. These electric power failures, which mostly occur unexpectedly, have various origins and are liable to have significant repercussions, due to the loss of operation of equipment that is important for the safety of industrial facilities. In this context, the internal electrical installations providing backup for all or part of a plant's installations are crucial. It is therefore important preventively to check their appropriate sizing, their satisfactory operation and their autonomy to ensure their availability and dependability when their use proves necessary.

1. Electric power failures due to various causes

Electric power failures are the result of numerous situations having very different causes:

- meteorological phenomena: thunderstorms are a common cause of electrical malfunctions, possibly even causing the prolonged outage of the external electricity supply of a plant (ARIA 38391, 50906, 55783). In some cases, these events are the cause of further damage independent of the loss of power supply, thus making crisis management by the operator more complex (localised floods on the site, overflowing of effluent basins due to heavy rainfall, lightning impacts that can constitute a potential additional hazard, etc.). In addition to thunderstorms, other meteorological phenomena such as storms (ARIA 61170) and floods can also cause the loss of electrical utilities at industrial facilities.
- other natural phenomena: forest fires, due to the damage which is caused to the external electricity network, but also power cuts decided on deliberately in this context by the network manager (ARIA 55907), can cause electrical malfunctions. Some animals also cause damage to the network, whether in industrial facilities (ARIA 53626) or outside them (ARIA 62720).
- equipment faults: various technical incidents can occur on internal installations (transformers, electrical cabinets, fuses, etc.), notably due to insufficient management by the operators of risks related to ageing of this type of equipment, or else on external installations (public electrical rooms, electric power lines, etc.). In both cases, these equipment malfunctions can cause the loss of electrical utilities (ARIA 60181, 61308, 61428, 63046).
- human intervention: the network manager can perform scheduled maintenance activities on the electricity network (ARIA 61336) or intervene unexpectedly (e.g. in the event of a forest fire, see above), causing power cuts.
- malicious acts: such acts can also cause the loss of electrical utilities, often for a prolonged time, in industrial facilities. They generally do not specifically target said industrial facilities, but the public electricity grid, e.g. by deliberately setting fire to high-voltage electric power lines (ARIA 58859, 60677).

2. Potential consequences that are often significant

Whatever the nature of the electrical malfunctions caused, ranging from sudden voltage fluctuations, liable to harm sensitive industrial facilities, to a prolonged electric power failure, and including repeated brownouts, this type of event is liable to have serious consequences for the industrial establishments concerned.

When electrical malfunctions impact critical facilities that are not designed to be shut down rapidly and unexpectedly (e.g., furnaces containing liquid metal: ARIA 59975, 60199), the associated potential consequences can be substantial. Indeed, for these events, the operating constraints are such that any loss of an electrical utility is liable to produce major irremediable effects (for example, permanent damage to an industrial facility in the event of prolonged cooling, or conversely the significant release of hazardous substances in the event of prolonged outage of the cooling system).

3. When the failure of backup electrical installations increases the tension...

One of the technical means for preventing the loss of electrical utilities is to set up dedicated internal electrical installations designed to back up all or part of the industrial facilities. However, these backup installations, where they exist, must be tested regularly and undergo appropriate maintenance.

Numerous malfunctions of these backup installations, observed on the occasion of proven losses of electrical utilities, are identified in the ARIA database. The events presented in the following pages constitute, among other things, examples of failures, which make crisis management by the operator far more complex. For example, generator sets may prove inoperative or have problems starting (ARIA 42670, 46789, 62019), or else encounter problems of coupling with the establishment's backed-up electricity network (ARIA 51377, 61923).

Failures of other devices responsible for maintaining the electric power supply at a facility in the event of a power cut (ARIA 59976, 61203, 61336) can also occur, which may cause a failure to switch from the main network to the backup network in the event of a power cut or else a malfunction of the UPS systems contributing to the maintenance of a backup electricity network.

4. Recommendations to prevent failures of backup installations

Feedback derived from power outage incidents on industrial facilities including the failure of backup electrical installations, taken from the ARIA database, teach us the following general lessons:

- provide for a backup electric power supply for all systems requiring it, with a power reserve capable of ensuring their operation at least during the operations to place the site in safety configuration, and sized taking into account the potential duration of the crisis;
- ensure satisfactory management of emergency response equipment, complying with manufacturers' service lives which could be related to the operating conditions (e.g. temperature) found at the place of installation;
- regularly perform maintenance of emergency response equipment and define the criteria to be verified (e.g. capacity for a battery) and ensure the availability of replacement parts;
- conduct routine drills and tests to detect anomalies during the implementation of compensatory measures or the switchover to backup networks;
- take special care during maintenance operations on one of the power supply channels in order to secure the operation of the other available channel(s);
- take into account the length of operation of compensatory measures (e.g. batteries) and plan ahead for replenishment (e.g. fuel for generator sets).

Numerous other recommendations relating to the loss of electrical utilities, beyond the prevention of failures which could impact the backup electrical installations, are available in a BARPI's Flash ARIA.

FLASH ARIA
December 2024

BARPI

Loss of electrical utilities: a short circuit leading to an accident!

Electricity is an essential utility for nearly every enterprise. Its loss can therefore be a cause of dangerous events, such as a fire or a release of hazardous or polluting substances, and very often entails significant operating losses. The management of these degraded situations cannot be improvised and must be prepared. The ARIA database lists more than 200 events affecting all sectors of activity.

Whether external or internal, transient or lasting several days, following a harmful natural event or an equipment failure, the loss of an electrical utility is a scenario that industrial firms must anticipate in order to manage the event independently and keep their installations safe.

To find out more

F A C T S H E E T

Emission of hydrocarbons followed by an outbreak of fire

10/03/2022

Port-Jérôme-sur-Seine (Seine-Maritime)

France

Oil refining
Electrical (failures)
Ageing
Modifications

THE ACCIDENT AND ITS CONSEQUENCES

On 10 March 2022 at around 1.15 a.m., following the failure of an electric cable, several installations of the distillation units of a refinery came to a halt.

The stoppage of block 17 and the cooling water towers of an adjacent block led to a halt in the inflow of cooling water to the condensers at the head of distillation tower T801. This caused a loss of vacuum in the tower and then the opening of the tower's relief valves, leading to a release of steam initially containing hydrocarbons. When it fell on hot spots, this mixture caused outbreaks of fire and the emission of fumes under the tower.

Over the half-hour following the start of the event, the in-house firefighters intervened and performed reconnaissance operations. The internal emergency plan was activated at 1.42 a.m. and the employees of the neighbouring establishment, located downwind, were confined at around 2 a.m.

This emission of steam and hydrocarbons lasted around 1.5 hours. Odours were perceptible in the environment. Analyses were performed by ATMO Normandie and by the firefighters of the departmental fire service from 3.15 a.m., especially for H_2S and SO_2. They showed no significant risks for human health in the vicinity of the establishment.

The internal emergency plan was lifted at around 4.40 a.m. The unit in question was restarted 3 days later.

Distillation units fractionate crude oil into various petroleum fractions (bitumens, lubricants, inputs for chemicals, fuels, gas). The "Distillation 2 or 17-1" unit comprises 2 distillation towers (T701 atmospheric and T801 vacuum) located in the centre of the site, south of block 17. The crude oil is distilled first in T701 to separate the lighter products from the heavier ones. The latter are then sent to T801 which fractionates the other products under vacuum in order to obtain vaporisation at temperatures of less than 410°C to avoid their thermal degradation. Diesel oils, oils and bitumen bases are thus separated. At the head of this tower, a mixture containing mostly steam and hydrocarbon vapours (diesel oil) is cooled, condensed and then separated..

THE ORIGIN AND THE CAUSES

The accident was caused by an electric power outage which caused a shutdown of the cooling systems and placed the distillation tower in safety configuration, leading at 1.26 a.m. to the opening of the relief valves located at the top of the tower. Hydrocarbons were vaporised and fell back on hot spots in the immediate vicinity of the tower in question, resulting in three fume release zones which were rapidly brought under control by the firefighters present on site at all times. The valves closed again at 2.58 a.m. as soon as the cooling circuits were restored.

The enquiry opened by the BEA-RI (Bureau d'Enquêtes et d'Analyses sur les Risques Industriels, i.e., Industrial Risk Investigation and Analysis Office) concluded that the electrical outage was due to tripping of the electrical safety systems following detection of a leakage current on one of the cables powering the installations. This outage had been caused by an accumulation of damage affecting the cable and in particular the insulating material, due to its ageing. Power was normally supplied by two redundant electrical links, but the cable failure occurred while the second link was undergoing maintenance. The electrical inspections performed by the operator were unable to assess the ageing and damage to the cable insulating material.

The enquiry also showed that the cooling circuit had been modified in the past, with the addition of an electronic control system on the steam turbines to improve their operating safety, and had been rendered completely dependent on the electric power supply. It was therefore unable to play its role in the course of this event.

FOLLOW-UP ACTION TAKEN

An inspection visit was organised on the day of the event, notably leading the inspection authorities for classified facilities to issue corrective action requests relating to:

- the time taken to alert the nearby firms;
- the organisation of the operator's control centre, in particular concerning reception of the authorities;
- the organisation set up to take samples outside the site.

A second inspection visit was conducted the day after the event, leading to the issue of corrective action requests and the sending of substantiating documents regarding:

- standby electrical facilities (batteries, electricity generator);
- the compensatory measures defined when redundancy of the two electric power supplies is not ensured, e.g. during works.

The operator's action plan was spread over several years, and other visits were carried out subsequently.

LESSONS LEARNT

The BEA-RI report drew the following lessons:

- electric power cables of industrial units, like other equipment, are subject to ageing mechanisms;
- this ageing can be monitored and anticipated by means of inspections on damage to the insulating material;
- triggering of a procedure to place an installation in safety configuration, which can protect the integrity of the installation and protect human life, can nevertheless have an environmental and health impact which should be taken into account in post-accident management;
- by using air sampling systems that can be mobilised rapidly, it is possible to measure the concentrations of substances in gaseous releases and to obtain an objective view of any environmental or health impact of an event.

The report also mentioned the following recommendations for the operator of the facility in question:

- establish a plan for enhancing the reliability of its power supply network through more regular monitoring of high-voltage cables based on various diagnosis methods and replacing them gradually, notably during major shutdowns;
- reconsider load shedding priorities in light of the hazard analysis scenarios;
- check whether the minimum duration of the standby power supply for the control rooms is sufficient to enable the technicians to control management of the installations in the event of a power outage;
- improve the speed of execution of air sampling by using canisters.

Release of gas at an underground storage facility

07/11/2022

Germigny-sous-Coulombs (Seine-et-Marne)

France

Release

Natural gas

THE ACCIDENT AND ITS CONSEQUENCES

On 7 November 2022, when the installations of an underground natural gas storage facility were idle, a monthly test was carried out on the generator set. This test resulted in a power outage on the fire alarm control panel, leading to the "ultimate safety shutdown" of the compression and treatment workshops (isolation of the workshops by closing the gas inlet and outlet valves) and then their decompression via the air vents located on a dedicated platform. The triggering of the ultimate safety shutdown system, which corresponds to the operation of a safety system, entailed the venting of 22,000 m^3 of natural gas, or approximately 14 tonnes.

The on-call teams intervened to identify the causes of this placing in safety configuration. After taking precautionary measures and changing the batteries of the fire alarm control panel, the facility was restored to operation two days later.

THE ORIGIN AND THE CAUSES

On 26 October 2022, or 12 days before the event, a "battery low level fault – fire alarm control panel" alarm had appeared on the monitor. This alarm had triggered corrective action by the maintenance team, which observed that one of the two batteries of the fire alarm control panel was inoperative (each module being provided with two batteries, including one on standby) and therefore proceeded to order a replacement battery. The maintenance team performed tests on the second battery which appeared to be still operational. It should be noted that the alarm on the monitor appeared whenever one of the two batteries malfunctioned; it could therefore disappear only after the first battery had been replaced.

On the day of the event, when this battery had not yet been replaced, and when the site was shut down, a monthly test was performed on the generator set. This implied switching off the facility's main power supply with a view to starting up the generator set. In the transition period after power supply outage/switching off and before start-up of the generator set (several dozen seconds), the power supply for the fire alarm control panel was supposed to be provided by a UPS system. But a UPS operating problem due to a battery defect was observed. On the module in question, the first battery had been inoperative for the past 12 days (see above) and had not yet been replaced. However, the second battery had also become inoperative since its operating test 12 days earlier, and its malfunction had not then been detected. This is because the alarm still present on the monitor was common to the 2 batteries and could have given the impression that the cause was only the known failure of the first battery that had not yet been replaced. This can be explained by the fact that alarm transfer is associated with the module and not with each battery. The operator had therefore not been informed specifically of the fault occurring on the second battery.

The power outage on the fire alarm control panel therefore triggered the ultimate safety shutdown of the compression and treatment workshops, leading to the release of 22,000 m^3 of natural gas.

FOLLOW-UP ACTION TAKEN

Following this event, the inspection authorities for classified facilities carried out an inspection visit on 30 November 2022 and asked the operator, in particular, to:

- examine the possibility of having a specific alarm for each battery (i.e. a total of two alarms for the fire alarm control panel) in order to detect any operating failure of the second battery when the first one has already been identified as such;
- implement the action plan defined following the event (the main actions of which are described in detail below);
- consider the possibility of reducing the quantity of gas released during an ultimate safety shutdown.

Apart from the immediate or specific actions on site undertaken by the operator, an overall review was initiated, to extend the approach to "planned" releases during drills.

LESSONS LEARNT

The main actions taken by the operator following the event were as follows:

- raising technicians' awareness of failsafe systems on the devices triggering an "ultimate safety shutdown"/"workshop safety shutdown";
- analysing alarm flows in the control room;
- planning battery changes beforehand:
    * replacement of the batteries whenever a drop in availability is detected during maintenance;
    * campaign for replacement of the batteries of chargers-UPS systems initiated following the event.
- updating the operating procedure relating to testing of the generator set by inhibiting the tripping of ultimate safety shutdown accompanied by compensatory measures (control room informed and operating personnel kept near the devices for manual tripping of ultimate safety shutdown);
- replacing the charger-UPS system in order to have a specific alarm for each battery of the fire alarm control panel and no longer a grouped alarm;
- examining the possibility of reducing the quantity of gas released during "ultimate safety shutdowns", including during scheduled drills.

This event also shows that the operating parameters or hypotheses for an installation or its safety systems can change over time. For example, what could have been considered when commissioning the installation as purely positive (effectiveness of operation of the safety system as configured) is now viewed through the prism of new environmental requirements (reduction of greenhouse gas emissions) and requires a review of established practices, without adversely affecting a facility's safety.

Discharge of effluents at a fertiliser production plant

29/03/2024

Montoir-de-Bretagne (Loire-Atlantique)

France

Fertilisers
Ammonia
Losses of utilities
Preventive maintenance

THE ACCIDENT AND ITS CONSEQUENCES

The plant produced solid fertilisers with an ammonium nitrate base. It is classified as Seveso upper tier. The nitric acid and ammonium nitrate production systems have been shut down since 25 September 2023 due to an ammonia leak occurring at that date on the lining of a pump in the production workshop. On 30 October 2023, the operator announced the permanent shutdown of fertiliser production and the conversion of the site into a logistics platform. An employment safeguard plan was initiated (approved on 22 October 2024 after the event).

On 29 March 2024 at 12.30 p.m., the plant's main electric power supply was lost. The standby generator set started up automatically, but was not coupled to the plant's electricity network: the systems were therefore not backed-up.

The electric power supply is essential to keep the liquid ammonia storage facility cooled (-33°C) thanks to the operation of the ammonia compressors, and to keep the ammonium nitrate heated in a hot solution (NASC, 130°C) thanks to the heat produced by the boilers.

At 1.30 p.m., the operator decided to start up its gas scrubber to prevent a pressure build-up in the ammonia tank. The outage of the UPS systems present on site led it to trigger its internal emergency plan at 1.55 p.m. A series of malfunctions and unforeseen technical events would disrupt and delay the return to a normal operating situation.

At 2.25 p.m., the operator managed to couple its generator set to the plant's electricity network, but the compressed air network needed to operate the valves was not operational. The "South" air compressor, which was normally backed-up, was out of order. The "North" air compressor was not backed-up. Moreover, the restoration of the power supply did not cause the UPS systems to switch to charging mode. The operator had to bypass them with the support of the supplier's technical assistance staff.

At 4.40 p.m., the "North" air compressor was connected to the backup network and the UPS systems were bypassed. The equipment start-up sequences were launched. However, defects on the automatic control system prevented start-up of the ammonia compressor and the recirculation pump of the NASC tank. Subsequently, the 16-bar boiler restarted but the supply of heavy fuel oil was not available (a maintenance operation was to be performed in the afternoon) and the supply of light fuel oil provided a limited power reserve of 20 hours.

The control system was restored at around 11.15 p.m. despite some persistent communication faults. The NASC recirculation pump was operational, but not the compressor. In the evening, the electrical equipment of the main high-voltage power supply switchboard was tested. This equipment was operational. Re-energising of the main power supply switchboard was undertaken the next morning. An electric crackling sound caused the operator to switch it off again to clean the busbar and connectors at the end of the morning.

On 30 March 2024 at 1.50 p.m., power to the plant was restored via the external electricity grid. The ammonia compressor was restarted after a technician from the supplier performed work on the automatic system. The gas scrubber was stopped. A delivery of light fuel oil was made to supply the 16-bar boiler. At 4.05 p.m., the 40-bar boiler running on heavy fuel oil was restored to operation. At 5.30 p.m., the internal emergency plan was deactivated.

During the event, 8,327m^3 of ammoniacal water was discharged into the Loire, which represents 2.88t of nitrogen. There was no release of toxic gas, nor fire, nor explosion. The event caused no casualties.

THE ORIGIN AND THE CAUSES

The BEA-RI (Bureau d'Enquêtes et d'Analyses sur les Risques Industriels, i.e., Industrial Risk Investigation and Analysis Office) opened an enquiry concerning this accident. The enquiry report concluded that the event was due to a combination of the failure of the plant's power supply and the failure of the generator set's power switch which meant that it could not be coupled before the outage of the UPS systems and automatic control systems.

As regards the cutoff of the main electric power supply, this was a consequence of tripping of the electrical safety devices by the public manager of the electricity distribution grid (ENEDIS) which could have been caused either by a fault on the line between the source substation (ENEDIS end) and the operator's plant, or by an insulation fault at the current transformer for the plant's main switchboard. A 2021 electrical inspection report mentioned the existence of processes of wear and latent failures.

As regards the generator set, it was not coupled to the plant's electricity network because of a contactor which remained in an open position.Finally, the enquiry report revealed that at the time of the events, the level of redundancy was severely degraded due to failures or work which affected certain items of equipment necessary for normal operation of the installations (air compressor, ammonia compressor, boiler), due to the inadequate obsolescence monitoring and preventive maintenance plan. Moreover, the announcement of a plan for conversion of the establishment had led to the postponement of scheduled renovation works. In this situation, all these equipment outages would delay the return of plant operation to normal.

FOLLOW-UP ACTION TAKEN

From the start of the event, the prefecture set up a crisis management unit (without activating the external emergency plan) in which the inspection authorities for classified facilities took part. 14 situation reviews were performed. A proactive inspection was carried out as of the morning of 30 March 2024. Samples were taken in the Loire by the operator and by the maritime police department. The INERIS emergency situation support unit (CASU) was called on regarding two points: to know the distance impacted in the event of a release of ammonia if the gas scrubber failed, and to determine the risks in the event of cooling of the NASC. A prefectural order requiring the presence of a second (mobile) standby generator set was signed by the prefect. Two press releases were drafted on 29 and 30 March 2024, and an extraordinary meeting of the site monitoring commission dedicated to this event was held on 11 April 2024.

LESSONS LEARNT

This event shows the importance of paying special attention to:

- ageing of the electric power supply substation. This ageing caused the electric power outage. Maintenance and renovation plans could prevent this risk. Furthermore, the availability of replacement electrical parts should be watched;
- testing of standby power supplies. This testing should not consist merely of starting-up of the generator set; it should also allow testing of effective powering of the installations to be backed-up whenever possible;
- knowledge of backed-up equipment and equipment without backup power, including by UPS systems, and knowledge of the power reserve of UPS systems. During management of the event, it was observed that the operator's knowledge was imperfect;
- backup of the equipment rendered unavailable during maintenance operations or outages. For example, the only backed-up air compressor was not available. Backup of the second compressor had not been anticipated;
- backup of automatic control system programming and operating parameters so as to facilitate their restarting after the event. Provide for these backups and make sure to distinguish between the automatic systems necessary for the safety of the installations and those necessary for operation.

Gas emissions at a chemical facility

08/03/2024

Salindres (Gard)

France

Losses of utilities

Electrical (failures)

Ageing

THE ACCIDENT AND ITS CONSEQUENCES

On 8 March 2024 at 2.10 p.m., an electric arc occurred on the high-voltage (HV) rack of the main internal power supply line (line 1) of a chemical site. A sound of explosion was heard from the boiler room. This event caused a complete outage of the high-voltage network, leading to the stoppage of all site's industrial facilities and the activation of failsafe instrumented risk management measures upon a power failure.

The site's internal emergency plan ("POI") was initiated and 18 of the facility's firefighters were deployed.

The backup power supply was normally provided by a generator set, but did not start automatically. The generator set was started manually only at 3.53 p.m. However, it stopped at 4.20 p.m. due to a generator fault. At 5.40 p.m., the operator managed to restore the current by using the second internal high-voltage line powering the distribution substations of the chemical site (line 2). The event occurred on a Friday, so the operator took the decision not to restart the industrial facilities for the weekend.

Two days later, at 8.19 p.m., another electric arc occurred on an electric power line of the HV rack. The operator suspected an electrical fire and took the decision to cut off the HV power supply for the entire site, then provided by line 2, and not to switch it on again once the outbreak of fire had been brought under control. Rounds were put in place to ensure monitoring of the shut-down systems.

To compensate for the lack of electric power at the site, 10 generator sets were installed from 12 March to power the systems regarded as critical. In particular, all the system safety and supervision functions could thus be restarted. The investigation and repair operations continued until 22 March.

Regarding the environmental impact, untreated releases into the atmosphere took place over a short period of time, leading in particular to a release of nitrogen oxides (NOx). The main consequences of the event were economic, with operating losses of about €2-3m for the site. The plant's industrial production facilities were effectively shut down completely for a total of 10 days.

THE ORIGIN AND THE CAUSES

The general electric power outage was due to two main causes:

- ageing of a high-voltage electric cable;
- malfunctioning of the HV electrical protection system located ahead of an internal substation.

These 2 factors created excessive loading of the cable of the main high-voltage line powering the chemical site. This cable gave way at the level of an old repair, resulting in the general electric power outage that caused the event.

All the site's electric cables had been audited by a specialised outside contractor in 2018, focusing in particular on their ageing process, which is exacerbated by atmospheric conditions (exposure to UV, frost). This initial state of the electrical installations made it possible to produce a plan for replacement of the cables according to their level of criticality based on their obsolescence. The cable suspected of causing the electric arc was to be replaced during the year.

The failure of the generator set to start automatically, which was an aggravating factor of the event, was due to the fault of a circuit breaker which did not open during the power outage, preventing islanding on the backup electricity network. After manual restarting, the generator set stopped after about 30 minutes due to a generator fault. While the generator set underwent starting tests and verifications every month, the test protocols did not provide for testing of the automatic network coupling control system. The risk of poor synchronisation had however been identified a few months earlier and the replacement of the generator had been agreed.

FOLLOW-UP ACTION TAKEN

An inspection visit was carried out following this event, at the end of which the operator was asked to:

- complete its accident report with a more thorough analysis of the causes, apart from the direct causes, and to specify the action plan implemented in order to prevent any recurrence of similar events;
- reinforce the measures for monitoring and prevention of ageing of the site's high-voltage electricity network in order to improve its dependability;
- improve the robustness of the backup electric power system in the event of an electric power outage in order to ensure its satisfactory operation.

In response, the operator produced an action plan aimed at preventing risks due to ageing of the high-voltage electrical installations and the associated backup electrical installations. Corrective and preventive replacement operations were performed on high-voltage cables regarded as high-risk. The site's standby generator set was replaced by a generator set of greater capacity allowing the performance of monthly starting tests including testing of the automatic network coupling control system.

LESSONS LEARNT

These events showed that, in addition to the routine testing and maintenance operations performed, the operator had to define an action programme to prevent risks related to ageing, for both the high-voltage electricity network and the backup electrical installations, by an approach similar to that used in the case of the French Plan for Modernisation of Industrial Facilities (PMII):

- production of an initial state of the HV electricity network and the backup equipment (manufacturers, ages, repairs already performed, state observed at the end of the last audit);
- definition of the particular procedures for monitoring the electrical installations of the HV network, specifying the diagnosis methods and monitoring frequencies to be adopted on the basis of experience feedback from accident research relating to electrical installations;
- determination of the criteria for the interpretation of inspection results and definition of thresholds for action depending on the faults detected: repairs, heightened monitoring, replacement and associated response times;
- definition of inspection reference frameworks to ensure the robustness and suitability of the repairs performed.

With regard to safety, the risk management measures identified in the hazard analysis are failsafe mechanisms, i.e. they adopt a fallback position (hence safety) in the event of a power outage. The satisfactory functioning of these measures during the event made it possible to limit its consequences.

FACT SHEET

Change Management - Anticipating and Managing Change

Industrial facilities undergo technical changes (processes, raw materials, etc.), organisational changes (operator, workforce, distribution and work rate, etc.) and changes of context (economic development, new standards, pandemic) during their operation. Change management involves adapting risk management to these developments to ensure they are kept under control. This entails first a revision of the risk analysis prior to the planned changes, which then leaves time to implement measures such as aligning procedures, making ergonomic changes or providing support for the technicians. Finally, the efficiency of these measures should be monitored, assessing their level of assimilation by the various actors, and adapting them if necessary.

1. Changes in industrial facilities can be a source of risks

1.1 Technical changes

Technical changes may concern:

- **changes of products, raw materials or suppliers.** The question of incompatible mixtures, for example, must be taken into account to prevent routine operations which are under control from resulting in an incident following such a change:

ARIA 59268 – 13/06/2022 – Loudun (Vienne) – France

A strong odour and a release of smoke were detected in the storage room of an industrial laundry. The personnel were evacuated and the neighbouring firm was confined. The reorganisation of chemical product storage was the cause of the event. Three hours before the event, the former formic acid tank had been filled with hydrogen peroxide. The tank had not been rinsed and cleaned before filling, although an incompatibility matrix chart was available on the site. There was no procedure governing product changes in storage tanks

- **process changes.** The effects of changes may materialise during work phases or as soon as they are implemented:

ARIA 50441 – 11/02/2005 – Alcantarilla – Spain

The loss of control of a chemical reaction led to a fire in a pharmaceutical plant. The damage amounted to €12m. The uncontrolled reaction was due to a change in the reaction temperature. To increase the reaction's efficiency, the temperature had been reduced from 50°C to 20°C. The accident occurred during the first production under these new conditions. No risk analysis of this operating change had been performed. The standards of the group to which the plant belonged did not take the risk of runaway exothermic reactions into account.

The effects can also materialise after a time lag, when equipment deteriorates gradually as a result of another hazard. In the following example, organisational failings meant it was not possible to detect the anomaly that had occurred:

ARIA 20541 – 16/04/2001 – Immingham – United Kingdom

In the gas separation unit of a refinery, a pipe section broke suddenly at an elbow located downstream from a water injection point, releasing a cloud of ethane, propane and butane which caught fire and exploded 30s later. Several fires and explosions occurred due to a domino effect. The unit was severely damaged, as well as other buildings on the site within a radius of 400m. Damage was reported on houses outside the site within a radius of 1km, and ejections up to 5km. The break occurred near a water injection point not planned in the plant's design. The pipe had undergone erosion and corrosion due to the injection of water, which had reduced its thickness from 8mm to 0.3mm. The enquiry revealed numerous organisational failings: lack of understanding of the conditions of pipe operation, inadequate inspection, poor change management. The technicians, inspection personnel and surveillance personnel did not know the real conditions of piping operation on the unit.

1.2 Organisational changes

Organisational changes may concern:

- **the breakdown of tasks among the various actors.** It is important that each actor – manager, technician, contractor – should know their role and their responsibilities in the firm following an organisational change. This is an issue especially on industrial platforms with interdependent facilities and for which the operator in charge of a facility may change following an M&A corporate action or a split-up. The event ARIA 62372 presented at the seminar illustrates this case.
- **the distribution and pace of work:**

ARIA 47253 – 07/10/2015 – Rillieux-la-Pape (Rhône) – France

In a detergent plant, 80,000 litres of bleach spilled into a retention basin. 30l of product built up in a low point of the rainwater network. The product was pumped into an empty container having contained acid retrieved urgently in the waste yard. A dichlorine gas release occurred and slightly intoxicated an employee. Four months before the event, the operator had eliminated the night shift responsible for transferring products between the storage tanks and the packaging lines. A production technician had initiated the transfer by starting the pump before opening the valve, which caused draw-off and then water hammer, partly detaching an elbow from the PVC piping. The production team had not been trained in this operation which had previously been performed by a specialised team, and no operating instructions existed for the transfer. The layout of the control console did not indicate the valve's position, and the retention basin level sensor was out of order. The technician could not be aware of the mistake from the control room.

- procedures and instructions, including for ancillary facilities:

ARIA 44619 – 30/10/2013 – Folschviller (Moselle) - France

In an industrial bakery, 62 people working in a clean room complained of headaches and nausea. They identified a smell of exhaust gas. The staff were evacuated. The clean rooms were kept at overpressure by an air treatment plant installed in the adjacent courtyard, enclosed on 3 sides and containing parking spaces. Recently, as part of the establishment of an emergency plan, the employees had received the instruction to park their vehicle on this parking lot in reverse gear. The vehicles' exhaust gases had apparently been captured by the air intake and disseminated in the clean room.

1.3 Changes of context

The context concerns the external factors which are imperative for the operator of an industrial facility, whether environmental, economic, social or regulatory. Some changes of context can be foreseen, such as the occurrence of dry spells in summertime. The event ARIA 59403, presented at this seminar, shows how efforts to save water during a drought resulted in a hasty change to the equipment, leading to the emission of toxic substances.

An increase in production with a constant process, in response to increasing demand, can also result in an incident, as shown by the event ARIA 61418, presented at this seminar. This example shows how insufficiently supported changes of organisation and context reveal latent hazards[1] in the equipment's design and ergonomics, reflecting process changes which reveal organisational defects.

Changes in the socio-economic context and the changes in the allocation of work which may result from them also generate new risks:

ARIA 62179 – 18/04/2024 – Hagondange (Moselle) – France

A fire broke out during the start-up sequence for a furnace in an iron and steel plant. The furnace was pierced, causing explosions. The technicians tried to tilt the furnace to stop the leakage of molten metal, but the fire on the hydraulic circuit caused a loss of control over furnace tilting. The technicians placed the furnace back in position using the backup console and placed it on jack stands to stabilise it. The firefighters extinguished the fire with foam. The shutdown of the furnace caused 235 people to be laid off for more than 8 days with an operating loss of €4m for the plant. During an inspection before charging the scrap metal, the technician had seen that refractory bricks were missing on the wall of the furnace, but had not reported the problem and had allowed the operation to continue. The missing bricks could have been due to an impact with the scrap metal during charging or the previous cast. The company's situation of receivership and a change of work shifts to 2x12h instead of 3x8h due to a shortage of personnel may have caused stress which resulted in this situation.

2. Managing change to prevent new risks

Change management tools can prevent risks due to technical, organisational or context changes:

- perform a comprehensive risk analysis when a change is planned on an industrial facility or on ancillary facilities. The analysis covers both transition phases and operating phases, and takes into account technical, organisational and human risk factors;
- verify the effectiveness of the risk management measures. The existing protective barriers should continue to fulfil their function when changing process. A knowledge of the latent hazards of a system can make it possible to support change with an approach of reducing the risk at source, by selecting suitable equipment or improving the ergonomics of the workstation, thereby limiting the risks of human error;
- consider the operating, maintenance and safety procedures and update them, to ensure that they remain appropriate for new processes or a new organisation;
- involve the staff in change: listening beforehand to the needs and actual practices in the field, training in the new operation of the systems, and support and follow-up to ensure implementation of the new procedures.

The change management approach is an approach which is planned beforehand and must be envisaged over time: it does not stop on the day of start-up of a new system.

1 Latent hazard: in the sense of ARIA terminology, a latent hazard is an underlying threat to safety. It requires a trigger to manifest itself in the form of a hazardous phenomenon. The presence of a high level of dust in a silo, leading to the existence of an explosive atmosphere, is a latent hazard. It will only lead to the hazardous phenomenon if an ignition source appears.

Dichloromethane leak at a chemical facility

18/01/2024

Tavaux (Jura)

France

Change management

Leaks

Prevention/protection/ intervention (measures of)

THE ACCIDENT AND ITS CONSEQUENCES

The site in question is an organic chemical site classified as Seveso Upper Tier, originally operated by a single operator (A), and which was partly sold to another operator (B) from 2015. As a result, the systems of the two operators are closely interlinked and interdependent. Certain common functions were assigned to one of the two operators for the entire site (supply of energy or water, treatment of certain waste, etc.): for example, administrative responsibility for the aqueous discharges of the whole site and their compliance at the point of discharge into the natural environment was assumed by operator B.

On 18 January 2024, a dichloromethane (DCM – CAS No. 75-09-2) leak occurred from a header which could be used to supply the refrigeration plant of operator A with DCM produced by B.

The leak was detected at 6.45 p.m. and triggered the rapid intervention of the on-site emergency services. Despite organising pumping operations, the leak reached unsealed ground. The quantity lost during the leak was estimated at 1.25t. The initial analyses in the site's water networks did not show the presence of DCM, but it was detected later in a boundary collection trench. The DCM had apparently reached a perched water table, then a storm sewer, before following this boundary trench up to the point of discharge into the natural environment. It caused the emission limit values (ELVs) in DCM flows to be exceeded from 25 January.

The analyses of wells located hydraulically downstream also revealed a DCM impact on groundwater from 2 February.

On 13 February, noting the persistent nonconformities at discharge, B informed the inspection authorities for classified facilities of this excessive level, and at the same time of the DCM leak on 18 January.

Faced with this information delay, the inspectorate scheduled a dedicated inspection visit on 20 February. This inspection visit revealed in particular that:

- neither of the two operators considered themselves responsible for the event of 18 January, and that each operator designated the other as responsible;
- the leaky header ("outgoing" header) had been replaced following the leak, but the "return" header, conveying the same fluid in similar conditions, had not undergone diagnosis for corrosion to check that it did not have the same damage;
- the storm sewer identified as a vector of pollution had not been stopped up. Following the inspection, B found a means to stop up this sewer and cut off this transfer channel;
- one of the wells that had been identified as impacted in the downstream water table was already connected to a stripping treatment system which could have reduced the DCM flow. However, this system was exceptionally idle during the event and was not put back into operation despite the observed impact. Following the inspection, operator A put this system back into operation, but most of the product had probably already been evacuated via the water table.

Compliance was restored on the DCM flow discharged into the natural environment on around 7 March.

THE ORIGIN AND THE CAUSES

A few weeks before the event, operator A had scheduled a maintenance stoppage for its installations and requested a test of the DCM header. This test had revealed signs of external corrosion. Repairs had indeed been requested, but the header had not been isolated and drained pending this repair work (in violation of the procedures of operator A). A manoeuvre by operator A on its refrigeration network apparently then caused water hammer on the header and resulted in its failure before the repairs could be performed.

In addition to these technical causes, the following phenomena were identified:

- when splitting up the site, the operators had drawn up an inventory of the installations and a breakdown of the headers. This breakdown was clear for the critical headers, which were therefore monitored by the respective recognised inspection departments of each operator. However, the event showed that less critical headers which had not required repairs since the split-up might have been omitted in defining this breakdown;
- although it thought that the header belonged to B, operator A had nevertheless commissioned and carried out work on this header, without obtaining authorisation from B. This anomaly could be explained partly by the fact that, before the split-up of the site, the two departments "producing" (B) and "consuming" (A) DCM formed one single department. The personnel of A may therefore have acted as though it were still the operator and specialist for all the installations;
- until the inspection of 20 February, each of the two operators had thus considered that the header belonged to the other, and considered itself not responsible. The intervention of the emergency services was indeed initiated by the department which detected the leak, but the post-event management suffered from a lack of coordination. This

dilution of responsibility between the two operators significantly impacted mitigation of the repercussions of the event. Moreover, neither of the operators had conducted an analysis of the event, nor the related reporting. This reporting was performed only by B, due to the ELV being exceeded at the point of discharge, which was clearly its responsibility. This point shows a real lack of communication between the two operators;

- however, the site's procedure stipulated that responsibility for an event is based on performance of the activity which caused it, and not on ownership of the installations. Even in the event of a doubt concerning ownership of the header, A was clearly the originator of the activities in question (maintenance operations on the header, maintaining the header in operation after detecting corrosion, a manoeuvre which caused the jolts), which also reveals a failure in the application of these joint procedures.

FOLLOW-UP ACTION TAKEN

Given the failings that had been observed, the two operators were subjected to follow-up administrative measures (emergency measures, formal notice) urging them in particular to establish a joint accident report (drawn up following the inspection) and to study the necessary strengthening of their joint governance.

Since this event, the inspectorate has encouraged them to restore synergy and active communication between the classified facilities monitoring departments of the two operators: drawing up joint reports, organising joint inspections, exchanges of information, etc.

LESSONS LEARNT

This case of separation of Seveso Upper Tier facilities between two operators represented a major change in the life of the site. This split-up of the site made it complex to manage and there was little feedback on which to draw. The main lessons learnt from the event are as follows:

- need for an exhaustive inventory of the installations, even those that are less critical. This inventory could be staggered over time. For this facility, it had still not been done almost 10 years after the split-up.
- the "human" impacts should be anticipated, e.g. regarding the feeling of belonging to a former department, even after its split-up between two operators.
- need for a very high level of communication on safety and environment issues, irrespective of any difficulties of a commercial or contractual nature. The application of procedures common to several operators must be verified by an identified department and be monitored by appropriate governance.

Since 2019, French regulation has set out provisions relating to industrial platforms. Companies operating interdependent facilities on a same industrial site can draw up a platform contract defining responsibilities of each party for shared facilities and appointing a platform manager. Accident prevention and management may be part of the platform manager's remit. These regulatory provisions encourage better governance of these industrial sites.

Hydrogen sulfide(H_2S) peaks in a food processing plant

24/06/2022

Châteauneuf-sur-Isère (Drôme)

France

Food processing
Waste / effluents
Fermentation
Toxic gases (H_2S)

THE ACCIDENT AND ITS CONSEQUENCES

On 24 June 2022, a peak concentration exceeding 1,000 ppm of H_2S (saturation of the sensor) for several hours was detected in the municipal sewerage network. Such a concentration can be fatal for humans. 13 days afterwards, the network manager identified the source, namely, a fruit processing plant. On 21 July 2022, 27 days after the first peak, another peak concentration exceeding 1,000 ppm of H_2S was recorded for 2 hours.

On 21 July 2022, a prefectural order instituting emergency measures prohibited discharges by the plant into the sewerage system. The plant's effluent pretreatment station was shut down, and it was then drained and disinfected with peracetic acid. 550m³ of untreated effluents were stored in the plant's firefighting water retention basin. They would be treated outside the site. The stoppage of discharges meant that the plant's production was stopped for 2 days. Works on the sector's sewerage system were prohibited for 1 month and all the firms in the sector had to check the tightness of their network (presence of water in the wastewater drainage plugs to prevent gases rising up from the sewerage system).

The factors conducive to the development of H_2S are as follows:

- temperature exceeding 15°C;
- pH between 5.5 and 8.5;
- anaerobic environment: dead legs in the networks, etc.;
- average rate of liquid flow less than 0.2m/s;
- presence of organic matter in effluents;
- source of sulphur (such as the sulphuric acid used as an acidity corrector, fruit).

THE ORIGIN AND THE CAUSES

At the end of the summer of 2021, the local authority detected some H_2S peaks in its sewerage system. In March 2022, the operator installed a temperature and H_2S sensor in the manhole on the outlet to the sewerage system in order to compare the data. It detected H_2S peaks exceeding 50 ppm during workshop start-ups, after stoppages at the weekend, and in periods of high temperatures, the occupational exposure limit being 10 ppm. The concentrations detected did not exceed 200 ppm and were short-lived. Other peaks were measured in June and July 2022. From the summer of 2022 the operator considered the possibility that fruit could be one of the sources of sulphur. However, it considered the H_2S emissions as a controlled risk, given the episodical concentrations.

The summer season is a time of busy activity for the firm. The process is changed several times each day depending on the fruit being processed. In addition to this customary situation in summertime, there had been a special context of drought and exceptionally high temperatures for several weeks.

During the event, the hydrographic area which supplied the plant with potable water had been on heightened alert for the past month. A prefectural order imposed a 40% reduction in water consumption on all industrial establishments. Since 2017, the operator had optimized its processes, enabling it to reduce its water consumption by more than 30% between 2017 and 2022. At the same time, production had increased by about 10%. Water consumption per tonne produced accordingly decreased from 5.95m³/t in 2017 to 4m³/t in 2022.

In the summer of 2022, the operator focused all its attention on compliance with the drought order that it had been ordered to comply with following an inspection visit. The temperature specifications for the production and storage rooms were increased, water recycling from the scrubbers was organised, and production was reorganised. A refrigeration unit was used in place of cooling towers to restrict water consumption. Cooling tower drainage accounts for 30% of the volume of wastewater used in pretreatment.

The pH level of the effluents was neutralised in the pretreatment buffer tank by injecting soda or sulphuric acid. Drainage of the buffer tank was performed in 100m³ batches. The elimination of discharge from the cooling towers and the reductions in water consumption in the production process resulted in a concentration of effluents and increased the residence time in the buffer tank until the high level was reached. The presence of stagnant sludges and a lack of aeration were noted.

Moreover, a malfunction on the automated production equipment cleaning system led to excessive consumption of detergent (soda). This increase required more intensive treatment by the injection of sulphuric acid (x3 compared with customary consumption) to neutralise the pH of the effluents in the pretreatment buffer tank.

The consequence of this situation was the extensive development of sulphate-reducing bacteria, with high H_2S emissions, in the plant's pretreatment unit. Moreover, the existence of dead legs and insufficient gradients on the effluent drainage network was conducive to stagnation and the creation of an anaerobic environment outside of the periods of emptying of the pretreatment unit, conducive to H_2S emission. The gas pockets were then released into the intermunicipal network during drainage of the buffer tank.

FOLLOW-UP ACTION TAKEN

The operator called on an outside contractor to analyse the situation. A continuous preventive treatment with calcium nitrate was organised using controlled injection into the buffer tank. This measure was able to significantly reduce the risk of H_2S production in the effluents.

The operator also replaced the main source of sulphur, namely sulphuric acid (used to neutralise the high pH of detergent solutions), with nitric acid. This acid, which costs 35% to 40% more, can also increase the water's nitrate content. This factor can inhibit the activity of sulphate-reducing bacteria. Furthermore, new gaseous H_2S measuring sensors were installed above the buffer tank and above the lift stations to supplement that already existing at the plant outlet. These sensors provide continuous measurement and recording. The in-line measurement of H_2S dissolved raises questions. Currently, the operator performs one measurement per week.

A curative treatment was made available on site for immediate action to destroy H_2S in the event of a measurement exceeding 2 ppm. The treatment uses sodium chlorite ($NaClO_2$). However, this product is toxic and when the pH of the effluent solution is acidic, highly toxic gas release could be initiated during mixing, thus making it tricky to use.

Lastly, the functioning of the wastewater treatment plant was modified:

- installation of an aerator to supplement the stirrer in order to avoid the resettling of sludge deposits and the formation of an anaerobic environment which foster sulphate-reducing bacteria;
- cleaning of the installations downstream of the buffer tank before each stoppage, and systematic treatment with sodium chlorite after the long stoppages occurring in the summertime pending changes to the network.
- recirculation of effluent from the lift station outlet to the buffer tank, with measurement of H_2S, before any discharge into the municipal network.

LESSONS LEARNT

Characterisation of the source term

The characterisation of the source term and the numerous factors influencing the production of H_2S are all issues to be taken into account to adapt the response to the event. The operator performed exhaustive research on the sources of sulphur in its processes: fruit, cleaning products, water treatment products.

Change management

The need for conservation of water resources on the national level requires a permanent reduction in water consumption by industrial firms, to which will be added temporary restrictions during periods of drought. The necessary process changes must be planned beforehand and accompanied by a risk analysis, in order to quantify the repercussions (in this event, on possible chemical reactions, on effluent concentrations, on residence times in the basin, and on the dosing of treatment products) and to implement suitable measures on water treatment systems to limit the production and release of H_2S. Following the event, the firm implemented such a risk review approach before any process change.

It is also important to check regularly that the assumptions taken into consideration in process sizing and risk analysis still hold. In this event this concerns the sizing of preventive treatment, based on a certain H_2S concentration range. That can avoid excessive product consumption or a reduction in treatment efficiency which could result in excesses. In order to ensure the efficiency of the solution under development and learn the residual risk, it is necessary to measure the total H_2S (dissolved + gas) in the effluents leaving the pretreatment unit. The total quantity of H_2S represents the residual risk of H_2S emission in the sewerage system and makes it possible to ensure efficiency of the treatment. These measures form part of a continuous improvement approach.

Regulatory framework

Since the discharge of effluents that could release toxic products is prohibited by ministerial orders, the discharge of H_2S is not usually covered by specific instructions. Following this event, the prefecture of the Drôme department established a departmental procedure for industrial firms to inform and warn the authorities if H_2S is detected: inform the authorities between 10 and 100 ppm with a systematic search for the cause as of 50 ppm, warn them as of 200 ppm or 100 ppm evolving over a period of 2 hours. An enquiry was made to 30 firms (food processors, tanneries) in the Drôme department with a request to measure dissolved and gaseous H_2S in summertime. Five plants have a definite H_2S problem. Thinking is underway to require of these plants the continuous measurement of gaseous H_2S before discharge into the municipal network. Further results are awaited on 7 other sites.

Complex interventions for emergency services

Leading an emergency operation is a difficult art which should never be taken for granted. Numerous human factors interact with surrounding parameters that are not controllable, in sometimes dramatic circumstances related to emergency operations. In this turmoil, the emergency operation leader must be able to decide "quickly and well" with the information available to him at the time. To do so, he will rely on the resources available to him and make use of various skills acquired through training and developed with experience.

1. General considerations on conducting an intervention

Training of emergency service management personnel aims primarily to respond to 2 requirements:

- develop leadership ability, by acquiring work tools and methods (operational management and leadership);
- assess environments, risks and appropriate intervention principles (operational techniques).

During routine interventions, the emergency operation leader will be able to manage the situation through instinctive responses or simple reasoning:

- are there any casualties? Removal from danger, checkup, urgent acts, regulation with the emergency medical service ("SAMU"), directing to a healthcare service and/or recommendations after regulation;
- is there a fire? What is burning, where is it burning, what access to it is possible, what risks of spreading, etc.

However, the emergency operation leader may be faced with more complex situations, for various reasons:

- the environment or the situation is not very well known or unknown;
- the events "do not go as they should" (malfunctioning of preventive measures, emergency response resources, etc.);
- the usual policies are not applicable;
- the intervention comprises numerous components to be taken into account (e.g., a fire, with casualties, a risk of spreading, collapse, or even pollution);
- the situation involves special kinetics or a special intervention zone, etc.

Several events are presented during the seminar to illustrate these situations (ARIA 60006, 60954, 61357, 63008). The emergency operation leader must be able to adapt and will have to conduct more in-depth tactical reasoning to define his strategy and his orders.

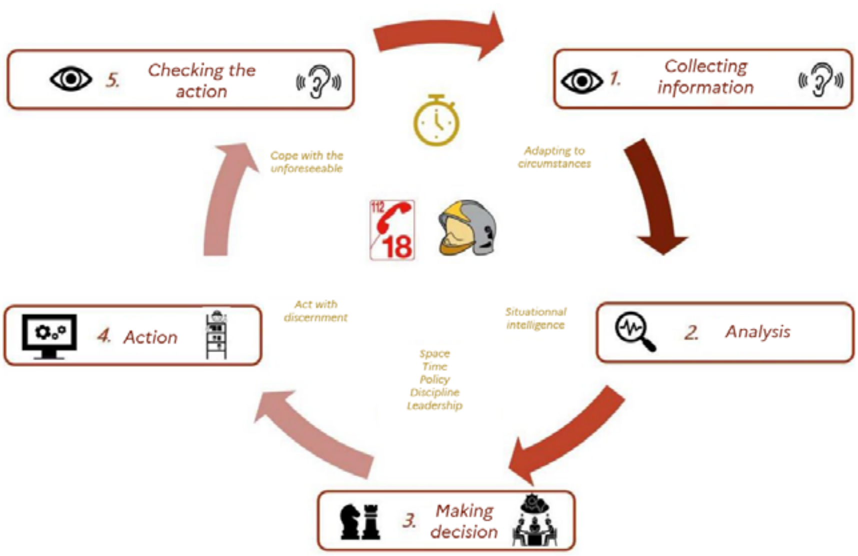
In the case of industrial risk, several components will facilitate his action:

- **the organisation of visits and/or drills on site provide a better knowledge of the location, as does the production of plans (classified facilities) or other files for receiving emergency responders;**
- **correct sizing and the availability of intervention facilities on the site;**
- **effective cooperation between the site operator and the emergency services is precious in ensuring the efficiency of the operation.**

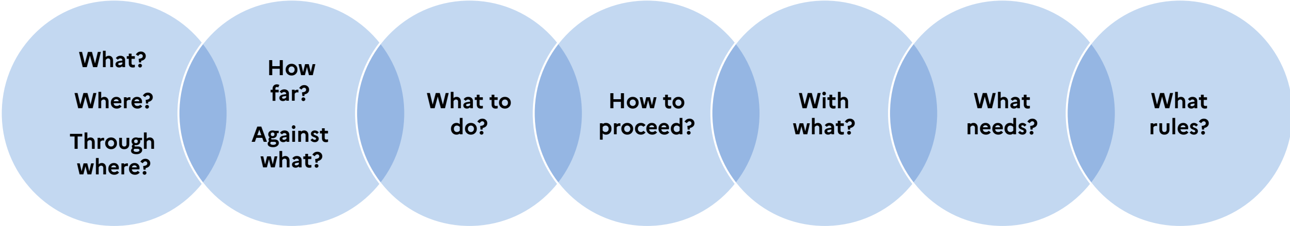
2. Illustration par le biais d'outils décisionnels

The Illustrations on this sheet are taken from the operational policy guide of the DGSCGC (French Directorate General for Civil Security and Crisis Management) on the exercise of leadership and the conduct of operations – June 2020 (second edition)

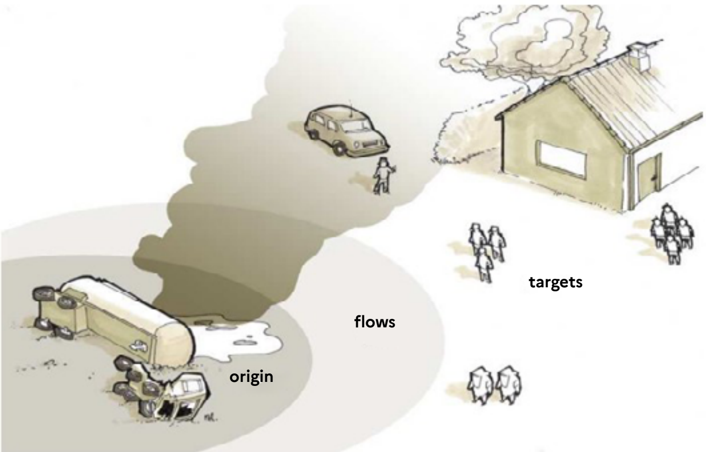
In a complex environment, the decision-making process of the emergency operation leader takes the form of a management loop, similar to the Deming Wheel.



His analysis will come within a tactical reasoning pattern, based on military doctrines.



He will supplement this with other methods, as necessary:

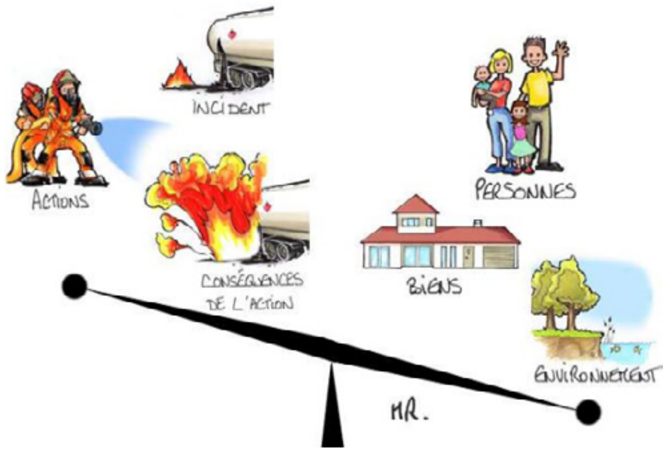


1- Systemic analysis (origin – flows – targets)

The systemic analysis replicates in a simplified manner the MADS-MOSAR model (systemic organised risk analysis method), organising the intervention zone into 3 systems: the origin of danger with all its characteristics, the potential targets (entities involved, third parties, property, the environment, etc.) and the flows to go from one to the other (smoke, gas, liquids, etc.). It aims to prevent overlooking aspects of the intervention and to avoid being restricted to what is immediately visible (for example, on a major fire, failing to be concerned about polluted firefighting water, without knowing where it is discharged, and having to treat pollution after the fire). It also aims to prioritise actions on the origin to the extent possible.

Chemical
Asphyxia
Panic
Fire
Pollution
Collapse
Weather
Electrical
Secondary accident
Explosion
Radiological
Toxic

2- Mnemonic methods such as CAPFPCWESERT, to avoid overlooking a risk



3- The benefit–risk balance

In some ways, we can see in this method a parallel with the principles of radiological protection: justification, optimisation and limitation. For the emergency operation leader, it is important to analyse whether the risks taken are justified (are they worth the trouble?).

On complex multi-component interventions, especially for events that could expand in time and space, forward planning work proves necessary and crucial for satisfactory conduct of the operations. For this purpose, the emergency operation leader can rely on a dedicated unit, rear-base support and a network of experts, the objective being to be "one step ahead" of the event and have the means required to deal with it.

Liaison with the other services can improve prevention, prediction and interventions. In particular, the Classified Facilities Inspectorate has a decisive role:

Before the event	• **check that the scenarios have indeed been provided for in the hazard study and taken into account in the instructions governing the activity of industrial facilities;** • **check that the preventive measures are implemented by the operator.**
During the event	• **support the emergency operation leader in a crisis, with the knowledge of the site acquired by its investigation and inspection activities (view objectively/compare the information given by the operator, etc.).**

Drawing lessons from past events can also facilitate and improve the conditions of intervention by the emergency services, especially in exceptional situations.

Fire at a household waste sorting centre

23/10/2023

Chêne-en-Semine (Haute-Savoie)

France

Fire

Sorting centre

Waste

THE ACCIDENT AND ITS CONSEQUENCES

To treat household waste from selective collection in Haute-Savoie and part of the Ain, i.e. 40,000 tonnes per year, an automated sorting centre was brought into operation at the start of 2023 in a dedicated 7,900 m² building at a multiple-waste sorting, transit and consolidation facility.

In the dedicated building, household waste from selective collection is deposited in a preliminary bay and then fed, on a First In First Out basis, into a mechanised sorting circuit comprising various types of screeners and separators. Finally, the sorted waste and sorting rejects are sent to a downstream bay, before being dispatched.

At 1.22 a.m., smoke appeared in the waste sorting building. The smoke became denser and the first flame could be seen at 2.44 a.m. on the surveillance images. The guard detected nothing on the cameras or during his rounds at 1.40 a.m. and 2.25 a.m., even though he clocked in nearby.

At around 3 a.m., several safety devices were activated:

- water cannons were activated in the incoming waste bay where there was no fire, but not those in the downstream bay for outgoing waste where fire was present;
- water curtains were activated on the openings in the firewalls for waste transit from one sector of the building to another;
- the audible evacuation alarm sounded in the affected building but not in the guard's office building;
- the firefighting water containment valves closed;
- the remote surveillance company was called automatically. However, it did not notify the facility's guard or the operator's personnel, as provided for in the list of persons to call.

At 3.15 a.m., the firefighters were notified by a motorist travelling near the facility and they arrived at 3.36 a.m. The guard did not notice their presence immediately and only opened the facility for them at 3.40 a.m. The fire was already significant by then. The firefighters used a public fire hydrant delivering less than the designed 140m³/h and then another hydrant several hundred metres away. The guard did not inform them that the site had a 380m³ water reserve, that they used only after the site manager arrived at 4.35 a.m.

At 4.08 a.m., the 900 m³ tank supplying the water cannons, the water curtains and the sprinkler system was empty. The fire then spread to the sorting line.

Traffic was suspended on the RD 1508 road running alongside the site and interchange 11 on the A40 motorway was closed for several hours, restricting access to the nearby industrial zone.

After several days of spraying and flooding the waste, during which the water from a nearby municipal swimming pool was used as a back-up, the firefighters declared the end of the intervention at 2.43 p.m. on 28 October 2023. The operator continued to monitor and sprinkle water for several days in case smoke appeared.

The event caused no victims, but the entire building and mechanised sorting line were destroyed, creating material damage estimated at 35 million euros.

From an environmental perspective, no lasting direct consequences were observed. In particular:

- all the fire extinguishing water was contained in the site's 1,795m³ basin and sent to treatment facilities. Practically the entire volume was available due to the lack of recent rainfall;
- analyses of atmospheric and surface samples taken by the firefighters showed no health risks;
- analyses of milk, lucerne and soil samples taken at a farm about 2.5km from the site showed no anomaly.

The fire also meant that the selective collection waste could not be sorted locally for several years, so it was sent to various sorting centres depending on their residual available capacity. These environmental consequences, although indirect, were not insignificant.

THE ORIGIN AND THE CAUSES

The sorting line had been stopped two days before the event, at 9.30 p.m. The personnel had left the establishment after cleaning the equipment. The only person remaining on site was a guard from a contractor company having the task of monitoring the images from the 36 surveillance cameras around the site from his office located in the adjacent administrative building, and doing regular rounds including clocking in of QR codes at various points in the establishment.

The cause of the fire is not known for certain, but it was probably due to thermal runaway of a battery in the sorting rejects, given the more than 24-hour time between the stoppage of operations and the outbreak of the fire, the place where the fire started and the absence of other identified causes.

The spread of the fire was facilitated by:

- the failure to detect the fire by the guard present on the spot, who had the necessary means and organisation to detect the first smoke;
- the untimely activation of the water cannons and water curtains, resulting in emptying of the dedicated 900m^3 tank and, subsequently, the operating failure of the sprinkler system designed to protect the sorting line;
- the failure of the water cannons to operate in the sector affected by the fire;
- the failure of the remote surveillance company to call the guard;
- the delay in opening the facility for the firefighters;
- the lower-than-expected firefighting water delivery and lack of knowledge of the internal reserves.

At this stage of the expert appraisal, the activation of the water cannons in a sector where there was no fire apparently resulted from the destruction of their electrical control system. The continued stoppage of the water cannons targeting the room in which the fire developed seems to be due to their setting in test mode, eliminating any possibility of automatic starting.

FOLLOW-UP ACTION TAKEN

Upon the proposal of the Classified Facilities Inspectorate, the Prefect signed an order for urgent measures, designed to:

- regulate the continuation of the establishment's activities not affected by the fire;
- ensure the safety of the site and in particular prohibit access to the building affected by the fire pending the opinion of an inspection agency;
- manage the waste affected or generated by the fire;
- have air samples and swabs analysed by the firefighters and do further environmental analyses if damage has been detected;
- subject restarting of the sorting centre to a prefectural decision established on the basis of a notice including in particular a hazard analysis.

LESSONS LEARNT

The following lessons can be learnt from this event:

- the vulnerability of this type of facility despite substantial detection and firefighting resources : permanent presence of a guard doing rounds, video surveillance by 36 cameras, remote surveillance, substantial in-house extinguishing equipment and water resources (internal reserve for water cannons, water curtains and the 900m^3 sprinkler system and 2 flexible tanks of capacity 190m^3 available to the firefighters);
- the under-sizing of the firefighting water retention volume established on the basis of extinction in 2 hours, whereas a fire can last several days (an available volume of 660m^3 as stipulated by the prefectural operating permit order would have been unable to ensure retention of all the firefighting water);
- the importance of the design policy for firefighting systems, in particular the possibility of automatic start-up of the protection systems in the event of an outage affecting their electrical control system;
- the importance of checking that the protection systems are not in test mode if such a mode exists;
- the importance of the human factor in accident scenarios;
- uncertainties regarding the flow rate delivered by public fire hydrants. Moreover, operators have no control over network management and the execution of a possible grid configuration;
- the importance of dividing the risks by isolating the stages in the process to avoid the risk of complete destruction of the industrial facility. In this framework, the reconstruction of the sorting centre provides for specific buildings to house the incoming waste bay, the sorting line and the sorted waste storage bay. The waste will go from one building to another on retractable conveyor belts;
- difficulties in insuring this type of facility due to its exposure to fire risk;
- the need for operational readiness in conjunction with the firefighting and emergency services (execution of an ETARE classified facility plan, a dossier on how to receive emergency responders, etc.).

Release of SO_2 in a container port

23/08/2022

Mannheim

Germany

Loading
Reaction
Releases
Evacuation

THE ACCIDENT AND ITS CONSEQUENCES

An ISO shipping container was delivered by road to the container port in Mannheim from a local chemical manufacturer, where it had been recently loaded with 195 steel drums containing ca. 21 tonnes of sodium dithionite. The container was accepted and positioned in a container stack awaiting its further transportation.

At around 14:35, after about 2 ½ hours, smoke was noticed coming from the container and the fire-brigade was called.

In coordination with the fire-brigade, the container was removed from the stack and placed on a free space on the ground.

There was a considerable rise in temperature, sufficient to discolour the paint on the outside of the container, and a build-up of pressure inside, which deformed the container walls. A cloud of dangerous gases containing sulphur dioxide was released from the ISO-container.

The fire-brigade set up water sprays to cool the container and also try to limit the spread of any dangerous gas clouds. They also consulted with the works fire-brigade of the chemicals manufacturer regarding possible strategies to deal with the event. It was decided to cool the container from the outside with water to reduce the rate of reaction. A hole was drilled into the container to allow the use of an endoscopic camera to view the internal situation within the container.

Initially, a safety zone for the emergency services of 200m was declared, which was later reduced to 50m. The container terminal operation was suspended. Within a radius of 1,300m, roads and railway routes were closed off, as were the port area and the neighbouring section of the river RHINE. Within this zone, residents were warned to keep doors and windows closed. Warning sirens were activated as well as the mobile-phone Warning App "NINA" (equivalent to FR-Alert in France). Residents in the immediate area were evacuated (ca. 80 persons) over night. During this evacuation activity, 16 police officers were exposed to sulphur dioxide fumes and required medical treatment, however no injuries were serious. The crane operator was also taken to hospital, but released shortly after.

Cooling was maintained for one week until no temperature rise due to chemical reactions could be measured.

The cooling water, which was sprayed onto the container, was collected within the rain-water system of the port. It was regularly analysed and then pumped to the town waste water treatment plant.

THE ORIGIN AND THE CAUSES

The main cause of the accident was in the loading of the container. The drums of chemicals were on wooden pallets (1,200mm x 1,000mm), five drums per pallet, each of which were completely wrapped in stretch film to make up a loading unit. However, the edges of the drums protruded beyond the edge of the pallets, which meant that there was an increased potential that drums could be damaged during loading. In addition, because of the way in which the pallets were loaded (neighbouring pallets were orientated 90° to each other), the tines of the forklift were longer than the shorter side of the pallet. Thus, despite awareness of the need for caution in the loading of the container, a drum was damaged by the tines of the forklift and in a manner that was not readily visible.

Sodium dithionite is a white powder used as a bleaching agent in the textile industry, which reacts with water and oxygen. Above 90°C, anhydrous sodium dithionite decomposes in air to sodium sulphate and sulphur dioxide. In the absence of air, it decomposes to sodium sulphite, sodium thiosulphate and sulphur dioxide at temperatures above 150°C. This means that once reactions within the container had been initiated, any increase in temperature would lead to a rapid escalation of the decomposition and release of sulphur dioxide. The hot and humid conditions in the container led to an exothermic reaction when the product was released. The large release of sulphur dioxide from the ISO-Container meant that a dangerous gas cloud covered the immediate surroundings.

FOLLOW-UP ACTION TAKEN

Once the ISO-container had cooled and no further reactions within the container could be detected, the ISO-container was opened under strict safety measures. The drums were recovered individually using a telescopic handler and manual handling. All personnel wore protective suits, gloves and gas masks. Each drum was numbered to identify it, inspected and assessed to detect any physical damage to the drum that was not due to the fire and any chemical reactions within the ISO-container. The drums were then crushed and sent for recycling. In total, two drums were identified as potentially having received damage during the loading operations and were sent to the Federal Institute for Materials Testing and Research for further investigation. In the end, one drum was identified as having been damaged by the tines of a forklift during the loading of the ISO-container.

Following this accident, the chemicals manufacturer decided to change the type of pallet used with these steel drums so as to ensure that the edges of the drums did not protrude over the edge of the wooden pallet.

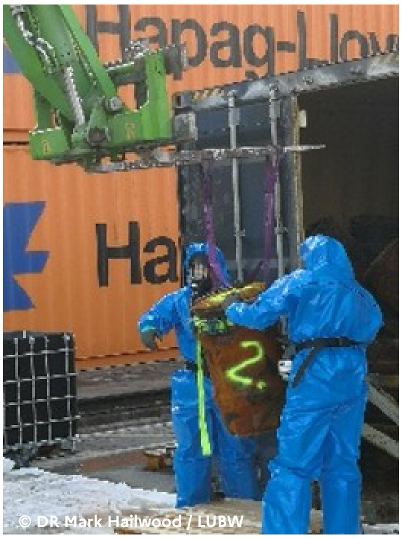
The operator of the container port introduced a more stringent monitoring of deliveries with ISO-containers containing dangerous chemicals. A thermographic screening of the outside of the container is carried out to check whether any hot-spots exists, which could indicate that a chemical reaction is taking place.

LESSONS LEARNT

There are a number of lessons to be learnt from this accident:

- during the loading of ISO-containers with drums of hazardous chemicals, care must be taken that drums are not damaged in any way, particularly as any damage may not be readily visible:
    * pallets should as far as possible be loaded so that drums do not protrude beyond the edges of the pallet;
    * pallets should be transported into the ISO-container in a manner which ensures that drums are not damaged, for example by the tines of the forklift or by impacts with the container wall or between two drums.
- emergency planning should consider the potential need to evacuate people from buildings close to the accident. Plans and measures should be adopted, which ensure that emergency responders are not exposed to unnecessary risks. These plans must be trained through exercises and appropriate personnel assigned to the task;
- ISO-containers in port areas may contain dangerous chemicals. It is not easy to know the state of the chemicals within the container from the outside. Unintended reactions cannot be discounted. Where potentially reactive chemicals are being transported, it may be appropriate to thermographically scan the container to detect any internal warming before adding the ISO-Container to stacks of other ISO-containers in the container port.

Cooling the ISO-container with a water spray



Recovering the drums from the ISO-container

Fire in a cold storage

14/12/2022

Villeneuve-lès-Bouloc (Haute-Garonne)

France

Cold store

Fire

Smoke control

THE ACCIDENT AND ITS CONSEQUENCES

At around 11 a.m., a fire broke out on pallets of boxes of frozen bread during handling by a forklift truck operator in a cold storage compartment. The establishment contained two storage compartments of 3,600m² each, where the only operations performed on site are of a logistical nature: packaging removal, storage, recovery and shipment of finished frozen food products intended for large and medium-sized retail stores. Within a minute, the forklift truck operator's manager had activated two extinguishers but was unable to bring the fire under control. After 4 minutes, the compartment was completely filled with smoke and incandescent debris were flying in the space in which about 3,700 pallets of foodstuffs were stored.

A technician called the fire department to report the presence of smoke, suggesting a "conventional" outbreak of fire in a store, leading it to deploy only about twenty firefighters. On arriving at 11.24 a.m., the firefighters established a safety perimeter and evacuated 20 workers. They performed reconnaissance in the compartment with a thermal imaging camera in order to find the fire source. They found themselves faced with dense white smoke and had difficulties finding their way inside the building (mezzanines, racks, etc.), which made reconnaissance more complex, since the camera revealed no hot spot.

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The water retention basin valve had been closed manually. The firefighting water reservoir, meanwhile, was unusable by the firefighters. The ammonia refrigeration system was not impacted. Moreover, the firefighters were faced with the drivers' refusal to leave the platforms without transport documents.

At around 12.10 pm, the main source was identified, and the firefighters activated the smoke vents. These vents, mounted on the roof, lead to the technical plenum and had no effect on the removal of smoke in the compartment.

Two two-person teams were committed to fight the fire directly, one with a fire hose and the other equipped with a thermal imaging camera in order to guide the first team in directing the jet. This phase presented new problems: the water was frozen (temperature of -18°C at the time of the accident), making the ground very slippery, but it also deformed the pallets stored on racks and made them heavier, threatening to collapse. Faced with these factors, the firefighters activated a long intervention procedure, sending human reinforcements to the site. Material reinforcements were also called for to perform manual smoke control for the compartment.

The firefighters made three breaches in the shell of the store as close as possible to the fire source with a hydraulic protection system in order to create outlets. They cut out the exterior and interior cladding in galvanised steel with a disc cutter and removed the polyurethane foam insulating core (20cm thick) with a pick. A heat recovery ventilator was then installed on the opposite facade, but it was unable to remove the hot smoke at the top. It was therefore decided to lower a firefighter with a SCBA to make a breach with the disc cutter and pick in the ceiling of the technical plenum. This operation was carried out at around 6 p.m. and proved effective, thus allowing removal of the hot smoke.

The firefighters stayed on site all night to keep watch on the hot spots, and they declared the fire extinguished at 3.21 p.m. the next day. In all, 47 firefighters were sent to the site during the event.

Eight days after the start of the event, smoke was detected on the pallet which was the source of the fire of the previous week. The firefighters were called on again and swiftly brought this outbreak under control.

There were no victims or environmental repercussions in this incident. The financial losses were significant (several million euros), due to the loss of all the foodstuffs stored in the two compartments (the compartment not reached by the fire was impacted by the smoke, making the food unfit for consumption) and the operating loss and material damage which, although the structure was not affected, were substantial.

THE ORIGIN AND THE CAUSES

The fire started during handling of a pallet of frozen bread by a forklift truck operator who was "sliding" pallets to remove several of them. During this operation, sparks appeared and set fire to the cardboard boxes at the bottom of the furthermost pallet. Friction of the wooden pallets against the rails generated sufficient energy to cause the sparks, which then set the cardboard boxes on fire. Nevertheless, the initial intensity of the fire remains hard to explain, given the nature of the products involved, namely frozen bread. However, one possible explanation is a phenomenon of fermentation which had led to the formation of flammable gases inside some boxes. The bread fermentation process generates acetaldehyde, a chemical compound whose properties are extremely conducive to flammability : it has a very low flash point (-38°C) and a Lower Explosive Limit (LEL) set at 4%.

The firefighters also detected the presence of localised outbreaks of fire on pallets of identical products located in the same bay, including on pallets which had not been handled. These observations seem to support this possible explanation, although it has not been able to be formally verified.

FOLLOW-UP ACTION TAKEN

An inspection was performed in the days following the accident. It revealed that the logistics activity had been suspended but that the compartments were maintained in deep freeze for health reasons. The operator had also given thought to disposal of the waste generated by extinction of the fire (water and material contaminated by the smoke) and also of the goods rendered unfit for consumption due to the thawing caused.

A prefectural order of emergency measures was issued following the second outbreak of fire 8 days after the fire, in order to require a 24/24 guard service long enough for the goods to be evacuated.

The compartment's activity has not resumed to date. The operator took measures to improve the fire alarm (elimination of the 5 min time lag in the event of fire detection, etc.), the warning system and reception of the emergency services.

LESSONS LEARNT

The accident highlights several crucial lessons for enhancing the safety of refrigerated logistics facilities and optimising operations if an accident occurs.

It illustrates the need to develop the fire risk culture in companies operating in similar environments. Regular and targeted training of employees, including various scenarios such as fires, could improve initial management of the incident.

Moreover, a knowledge of the constraints related to temperature and operational preparation for this type of situation is also a challenge for the firefighting and emergency services, during all phases of the intervention (reconnaissance, firefighting and protection, excavated material, etc.).

The absence of a smoke control system for the compartments, authorised by the French regulations under heading 1511, raises questions concerning its compatibility with the operational needs of the emergency services, since the rapid removal of smoke facilitates the intervention and improves safety for the firefighters, while reducing the scale of the damage. This factor seems to have contributed to the scale of the fire.

Silo fire

10/08/2023

La Rochelle (Charente-Maritime)

France

Silo
Fire
Cereals
Coordination
Inerting

THE ACCIDENT AND ITS CONSEQUENCES

At around 8 a.m., a fire broke out at a height of more than 50m, at the level of the roof of a concrete cereals storage compartment of a port silo. This compartment formed part of a silo with 19 compartments laid out in 2 parallel lines of 9 and 10 compartments, each with its silage gallery. The operator initiated its internal emergency plan. The fire reached the silage gallery on the compartments and then spread inside the gallery. A large plume of black smoke was released and was visible several kilometres away. The emergency responders established a 100-metre safety perimeter and evacuated about twenty employees. The fire in the compartments' gallery was stopped in the morning by the firefighters on the eighth compartment of the series of 10. Due to the composition of the roof of the compartments (PVC liner, bituminous waterproofing, glass wool insulating material and steel tank), the fire spread inside 8 compartments and reached the grain stored in 7 of them (the 8th compartment, the starting point of the fire, was empty). The strategy adopted by the emergency services was therefore to produce a foam blanket at the top of the compartment and inject nitrogen at the base of the compartment in order to stifle the fire sources. The firefighters' work conditions were perilous ; personal protective equipment had to be used to move around at a height, and a lifting arm was needed to transport the hoses and hence foam into the compartments. A team of firefighters specialised in technological hazards took atmospheric readings which proved to be below the smoke toxicity thresholds. Geometric inspections of the gallery and silos showed that the structures had not moved.

Three days after the start of the incident, the 2 compartments not affected were emptied via the usual emptying circuit and the cereals were stored on another part of the silo.

The fire was declared extinguished on all the compartments after 15 days of intervention by the firefighters. Temperature and CO content were monitored by the operator every day. Four days after the emergency responders departed, this monitoring revealed a significant temperature rise (98°C) in a barley compartment, suggesting the start of fermentation. A foam blanket was therefore produced by the firefighters at the top of the compartment, which was inerted once again. The operator then had to empty the compartments without waiting, starting with those containing barley. Emptying of all the silo compartments under nitrogen, i.e. 53,000 tonnes, took one and a half months.

Gallery fire

The total consumption of nitrogen related to the fire (extinction and silo emptying) was 163,000 m^3. The grain removed was classified into 4 categories according to its moisture level and smell (food sector, animal feed, anaerobic digestion and incineration), then stored according to its category in buildings rented for the circumstance.

The facility's activities were disrupted for several days and the incident caused fears of a food supply failure in a number of foreign countries. The action of the emergency responders made it possible to save 75% of the cereals contained in the silos and send them to the sectors originally planned (food or animal feed). 30% of the facility's storage capacity could no longer be used. The cost of the incident was estimated at approximately 20 million euros.

THE ORIGIN AND THE CAUSES

Repair work on roof waterproofing for the storage compartments had been started several months ago by an outside contractor. The roof of the compartment, which was the starting point of the fire, was undergoing work the day before the fire. At the end of the day, the tools consisting of a thermal welding machine and portable electric equipment fitted with Li-ion batteries had been left on the roof sheltered by the gallery. A storm broke out during the night.

The next morning, when it came to recover its tools and equipment remaining on the roof, and after switching on the equipment, the works contractor noted a release of smoke and then a flare.

An expert legal appraisal was unable to identify the source of energy giving rise to the fire.

Several tests were carried out simulating the conditions of the outbreak of fire, but none of them was able to reproduce the scene described by the contractor company performing the works. The presence of Li-ion batteries cannot by itself explain the speed of propagation and intensity of the incident.

The conveyor belt caught in the fire had been purchased in 2010 and installed in June 2014, and was flame retardant. To ensure that the belt had kept its properties, a portion not reached by the fire was sent for analysis, which showed that it had preserved its flame retardant nature. The presence of the wooden floor of the gallery fostered spreading of the fire.

FOLLOW-UP ACTION TAKEN

Upon the proposal of the Classified Facilities Inspectorate, the Prefect signed two orders for urgent measures. The first one, the day after the start of the fire, was designed in particular to:

- halt the activity of the 19 silo compartments;
- require that the operator take all necessary measures to control and contain hazardous phenomena related to the accident in conjunction with the departmental fire service (SDIS) (provision of internal and external resources, etc.);
- restore thermometry in the 9 compartments of the opposite line not affected by the fire and, failing that, in the meantime, take daily readings of the CO and O_2 parameters;
- force the operator to cover the costs entailed by all the measures taken because of the accident.

The second order signed one week later allowed the operator, under the supervision of a thermal imaging camera, to empty the compartments of the opposite silo line not affected by the fire and then start filling them again when the emergency responders had left the site.

This accident gave rise to an unscheduled inspection visit more than six months after the outbreak of the fire in cooperation with the BARPI. It showed that the operator had a robust organisation to manage subcontracted works and the associated risks, and controlled the silo management process.

LESSONS LEARNT

1° Planning and testing

The classified facility subject to permit had an internal emergency plan, stipulated by prefectural order, even though the national legislation does not require it for this type of establishment. For their part, the emergency responders had established an ETARE classified facilities plan. The implementation of these two plans and the associated drills enabled the operator to acquire experience of crisis management and enabled the departmental fire service (SDIS) to obtain a better knowledge of the plant. Furthermore, several years previously, a real-world nitrogen inerting test on a compartment had not worked, and this had alerted the operator to the need to have an expansion skid to convert liquid nitrogen into gaseous nitrogen. A second test had made it possible to achieve effective inerting of a compartment and acquire statistical data on the time needed to obtain effective inerting and on the quantities consumed. This data was used by the departmental fire service during the fire.

Nitrogen inerting

2° Excellent operator/SDIS/DREAL (Regional Directorate for the Environment, Planning and Housing) cooperation

Thanks to the performance of internal emergency plan and inerting drills, the operator, the departmental fire service and the DREAL referral inspector for the facility had already worked together and knew one another, which largely contributed to smooth communications during management of the event.

As of the initial hours of the fire, the departmental fire service requested the presence on site of the referral inspector. The DREAL's knowledge of the neighbouring firms made it possible to coordinate information from the Seveso facilities concerning water protection of their plant and management of the adjacent hydrocarbon pipelines. The presence of the DREAL on site was an asset in searching for a surveyor and taking orders for urgent measures. It made it possible to follow the evolution of the accident in real time and the strategy adopted. During this event, the operator's behaviour should be emphasised: it was proactive in making a 72m lifting arm available for the firefighters and agreed, without any official order, to all the proposals made during discussions concerning reconstruction of the plant.

3° The benefits of experience feedback to improve plant

After emptying the compartments, several discussion meetings were held between the operator, the departmental fire service and the DREAL in order to share the difficulties faced in fighting the fire and the improvements that could be made. The main purpose of the proposals was to confine the fire to a single compartment. For example, the wooden floor of the gallery on the compartments was rebuilt in aluminium. A double flight of stairs was installed so as to avoid taking the hoop ladder and to facilitate access for the emergency responders. The compartments were identified outside and inside. New footbridges were installed between compartments in the same row and with the opposite row of compartments to make the path easier for the emergency responders. The firefighting appliances were made more reliable by doubling the dry risers and installing additional pumps to obtain a pressure of 10 bar at the top of the compartments. In addition, the roofs have marking identifying the cut-out zone for foam injection, and a crane capable of lifting 500 tonnes of material was installed on a new platform at the top of the silos. Smoke control was restored by creating louvers. All these measures were also applied on the opposite line of compartments not affected by the fire.

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.

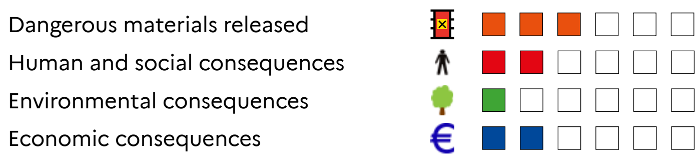
Further to difficulties which stemmed from the attribution of an overall index covering the consequences that are completely different according to the accidents, a new presentation of the European scale of industrial accidents with four indices was proposed. After having completed a large consultation 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.

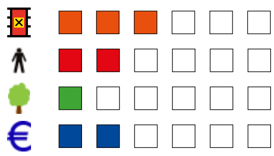
This presentation modifies neither the parameters nor the rating rules of the European scale.

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:



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 %	1 to 10 times the threshold	≥ 10 times the thresholdl
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.
** The accidental nature of an explosion will be demonstrated by the achievement of one of the 17 other criteria.

	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 consequencesales	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 m³) *	V < 1000	1000 ≤ V < 10 000	10 000 ≤ V < 0,1	0,1 million ≤ V< 1 million	1 million ≤ V< 10 millions	V ≥ 10 M
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.

	Conséquences économiques	1	2	3	4	5	6
€15	Property damage in the establishment (C expressed in millions of €)	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 €)	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 €)	–	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 €)	0,01 ≤ C < 0,05	0,05 ≤ C < 0,2	0,2 ≤ C < 1	1 ≤ C < 5	5 ≤ C < 20	C ≥ 20

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