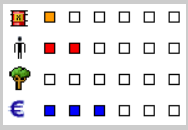
Inadequate use of available feedback

Explosion of a sulphuric acid tank during hot work

ARIA 36628 – 04/08/2009 - 76 - Gonfreville-l'Orcher

20.16 - Manufacturing of basic plastics



An empty 100-m³ sulphuric acid (H_2SO_4) tank exploded at 9:15 am at a chemical facility. Installed overlooking its retention basin at a height of several metres, this "F2"-type tank was blasted and fell to the ground nearby. The incident caused the scaffolding, set up to provide maintenance, to collapse, bringing down 3 plant employees and 2 subcontractor personnel. Two members of this crew suffered serious injuries : one of the plant employees sustained cranial trauma after falling around 10 metres, while a subcontractor got pinned between the tank and the scaffolding with severe injuries to the face due to discharges from the grinder he had been using.

The plant's internal emergency plan was activated, both in-house and external emergency responders arrived on the scene. The injured were evacuated to hospital ; the site operator informed the local prefecture, town halls and the general public. The classified facilities inspection authorities proceeded with an investigation.

The tank had been temporarily sealed on July 18th, using an impermeable box, following the discovery of a leak on July 16th. Scheduled for repairs at the beginning of August once it had been completely drained, the tank was rinsed with water over the weekend of August 2nd, subsequent to which a subcontractor installed the scaffolding required to perform repairs, allowing for access to the tank and a platinum insulation coating of the process. A plant employee was climbing into the tank to open the cover when the explosion occurred.

The accident appears to have ensued from the accumulation of hydrogen (H_2) at the top of the container and then caused by ignition of the combustible mix formed with air when the grinder cut its way through corroded bolts in the tank cover manhole. The tank was torn apart over half the circumference of the shell / bottom seam, while its anchorages were pulled out. Also, the tank had only been rinsed once; this fact supports the hypothesis of insufficient tank rinsing, which in turn led to acid attack of the metal with a release of H_2.

Available feedback had indicated several explosions of H_2 following the attack of steel tanks by diluted acid (ARIA 23705 on this very same F2 tank in 1989, but also at other sites - ARIA 169, 2278, 31082).

Given the succession of accidents arising over the months leading up to the accident in the petrochemical industry as well as in the transport of hazardous materials by pipeline, a special meeting devoted to industrial safety and environmental protection issues was organised in September 2009 between the Secretary of State for Ecology and key industry leaders. These industry representatives forwarded a series of proposals intended to improve the safety of their installations, by means of tightening controls over facility ageing and maintenance, while agreeing to pay greater attention to ecologically sensitive zones as a step towards enhancing species protection and preserving protected zones.

Inadequate use of available feedback

The feedback from previous accidents constitutes one of the foundations of technological risk management approaches. Such experience-based information must be of assistance in significantly reducing both accident frequency and the seriousness of consequences. Accident analyses offer a source of progress to the extent that lessons drawn are systematically transmitted to potential users and operators [1].

As revealed by the repetition of similar accidents in the ARIA database, these feedback processes, which are quite demanding, remain inadequately organised and applied. They are however intended to be a permanent part of the heritage from industrial sites and from industry in general, in the same way as corporate culture or technological breakthroughs.

The feedback process may be approached using several dimensions [2] :

- The vertical dimension, which encompasses the communication of information within a given entity ; this dimension implies a series of balanced and sustained exchanges between the actors at a site or within an industrial group : senior management, HSE (Health, Safety and the Environment), site foremen, technicians and subcontractors ;
- The horizontal or cross-sectional dimension, which encompasses exchanges external to the given entity ; this dimension requires broadening the dialogue engaged with the industrial sector to sectors involved in comparable issues, both in France and abroad, so as to expand and share knowledge and lessons, with the aim of achieving progress at lower cost ;
- Lastly, the temporal or historical dimension, which constitutes the very essence of feedback since lessons cannot be interpreted and applied without a record in one form or another : incident data sheets, summaries, best practices, professional standards. Repeated reminders regarding this historical record are needed to jog the memory when one of these hazardous processes is being considered for implementation.

At the beginning of the 20th century, Europe's chemical industry was heavily hit by several major accidents tied to the widespread manufacturing of nitrogenous fertilisers. On July 26, 1921 in Kriewald (formerly German Silesia), the "dislodging" of wagons filled with ammonium nitrate using explosives caused a detonation killing 19 (ARIA 17974). Less than 2 months later, on September 21st, in Germany's Oppau plant, blasting work on a pile of aggregated fertiliser mix containing ammonium nitrate and ammonium sulphate produced a detonation responsible for 561 deaths, 1,952 injured and the near total destruction of the town (ARIA 14373). Twenty years after that, in Belgium, explosives were still being used to disaggregate a pile of ammonium nitrate, resulting in another several hundred deaths at Tessenderlo (ARIA 17972). These three explosions highlight the inadequacies of circulating feedback among similar sites over a narrow time frame. Despite the production of asphalt mixes to subsequently avoid nitrate aggregation, several detonations of ammonium nitrate still occurred in succession, causing many victims and significant property damage, both in France (ARIA 5009 and 14732) and abroad (ARIA 535, 6268, 12271 and 11145). This background confirms the complex characteristics (e.g. chemical composition, particle distribution, density, humidity) associated with these categories of products and their detonation potential under certain conditions (notably type of mix, hazardous outcome when reacting with other materials or pollutants, temperature, confinement) that some had considered definitively removed from industrial sites, up until the Toulouse disaster in 2001 (ARIA 21329).

The accident at Gonfreville-l'Orcher (**ARIA 36628**) provides an illustration of how processes have failed in both their historical and cross-sectional dimensions. The same type of accident had already occurred 20 years prior on the same site and even on the same tank (ARIA 23705), but since at the time of the first incident no consequences other than property damage had been observed, the occurrence was noted in the facility tracking file, yet without drawing enough of a lesson to caution workers 20 years hence about the risk of forming a hydrogen cloud when the tank has not been sufficiently rinsed. The steel attack by acid, though diluted within a confined space, still led to the classical accumulation of hydrogen and formation of a highly-explosive atmosphere. Comparable accidents occurred at sites managed by other operators, whether in France (ARIA 169 and 31082) or abroad (ARIA 22278): the same product (sulphuric acid), same type of equipment (storage tank), same cause (acid corrosion of the metal and gas ignition by a relatively weak energy source or by heat emitted during hot work for example). Available accident records also contain many cases of hydrogen explosions due to the corrosion of metal containment around facilities (tanks: ARIA 16467, 24977 and 28569; pipelines: ARIA 29864; reactors: ARIA 2301 and 34921) in the presence of other acids.

Along the same lines, too many explosions still occur involving storage capacities containing combustible atmospheres during hot work on industrial sites, in France (inflammable vapours: ARIA 177, 1960, 4869, 5232, 8988 and 12038 / hydrogen: ARIA 23705 / dust: ARIA 8781,13357, 21241, 27280 and 31588) and abroad (inflammable vapours: ARIA 120, 7635, 11345, 21737, 22998, 25087, 33574, 34602, 35371, 38415, 38557, 38595, 38596, 38599, 38600 and 39076 / hydrogen: ARIA 22278 and 27273). The scenario always remains more or less the same: works are carried out by welding or grinding on a storage container even though verifications of the potential for atmospheric explosion inside and adjacent to the structure have not been conducted either prior to or during the works, or such verifications had not been adapted to the risks present (in terms of location and frequency), or else the facilities had not been cleaned of dust beforehand (ARIA 8781 and 21241). Given its seriousness and recurrence rate, this problem has given rise to the publication of many documents and videos as part of awareness-building campaigns (combustible gases [3], dust [4]). It is also quite striking to observe that at the same site and just 8 days before the sulphuric acid tank explosion, hot work (involving grinding) performed by a subcontracted firm had accidentally ignited a fire in a storage basin containing hydrocarbon sludge (36561).

While the major accident most often occurs with a low probability at the scale of an industrial plant, this relative improbability compared to the probabilities correlated with other risks in society is still capable of biasing the perception held by actors reasoning over short time frames and in restricted environments. This distortion on both the temporal and spatial scales could lead to a partial analysis that underestimates the possibility of serious accidents occurring at a given site. The historical / cross-sectional dimension is applicable to this context, in considerably widening the pool of experience to speed progress at lower cost by incorporating the experience gained from managing difficulties previously encountered by other actors.

Although the use of feedback seems complicated and costly, its contribution to installation safety is extremely valuable: feedback enables identifying and preventing accidental situations that cannot be detected by any other means. Both the internal and external dialogue required to manage feedback also produces indirect contributions, in the technical, economic and social arenas thanks to the resulting correlations and high-quality decisions. Feedback offers a powerful tool towards achieving all of a company's strategic objectives: not just safety, but also costs and productivity.

Implementation of this feedback approach however remains highly individualised from one activity to the next and from one group or establishment to the next. The underlying organisation is now highly sophisticated in some cases, while remains in its very nascent stages or follows no standard protocol in other cases. It is a common assertion for those entities and individuals that have experienced a serious accident to be the most dynamic behind this effort, since the cost of the accident often turns out to be much greater than the cost of prevention. The room for progress still appears to be substantial.

The conditions for achieving progress apparently lie in the following :

- A drive demonstrated by the company's top management that motivates employees and subcontractors ;
- A culture that permeates the professionalism of actors, who are encouraged to rely upon their daily experiences as a source of instruction and guidance in how to manage accidents, incidents and basic deficiencies (see provisions in the SEVESO Directive relative to overseeing the integration of feedback into the safety management system) ;
- An organisation and methods suited to each sector and each company, making it possible to observe, collect, prioritise and process the events ;
- A setting that encourages actors to recognise the benefit of involvement in the feedback approach (emphasis on the positive effects, closer contact with the field). Actual benefits often go beyond simple accident prevention and span a broad spectrum of risks the company may potentially face.

In the absence of unlimited resource allocations, a site operator may elect to implement this feedback approach over the long term in a way adapted to the facility's resources, which depends on whether the approach lies at the core of the safety management system and whether the key challenges have been understood by the entire company (field staff, site foremen, executive management). In this pursuit, the guide published in French by the SPPPI PACA agency proposes a methodological tool for the simple implementation of an event-based feedback system (from incidents or accidents) in small-sized entities [5].

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[2] INERIS - The organisational failures of feedback, December 2009.

[3] U.S. CHEMICAL SAFETY BOARD (CSB) - Seven Key Lessons to Prevent Worker Deaths During Hot Work In and Around Tanks, February 2010.

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[4] BARPI - Work carried out in silos containing plant products, Hazard!

INRS-ATEX - Application of the regulation relative to explosive atmospheres: Methodological guide

MEEDDAT - State-of-the-art guide on silos for application of the Ministerial decree relative to the risks presented by silos and storage installations containing cereals, grains, food products or any other organic product releasing combustible dust, Version 3, 2008.

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[5] SPPPI-PACA - Good practice guide: Feedback on industrial safety for small and medium-sized enterprises, November 2008.

Accidents whose ARIA number has not been underlined are described on the Website :

www.aria.developpement-durable.gouv.fr

ARIA 120 - July 7th, 1989 - THE NETHERLANDS - FARMSUM

20.59 - Manufacturing of other chemical products n.c.e. (not classified elsewhere)

Inside a molecular sieve plant, an ammonia tank was placed back into service after welding a new bottom ; afterwards, the evening shift carried out filling tests without making note in its end-of-shift report. During the next shift, a new series of repairs were conducted on the tank, which was assumed to be empty. When grinding of a pipe, sparks caused a deflagration of the confined ammonia vapours along with the ejection of the tank bottom a distance of 60 m against one of the site's administrative buildings. A hissing sound prior to the explosion alerted employees, and as a result none were hurt. The tank had contained 50 litres of 25% ammonia.

ARIA 169 - 09/08/1989 - 69 - SAINT-FONS

20.59 - Manufacture of chemicals n.c.a.

Grinding operations were scheduled on a tank having stored sulphuric acid. All operation procedures (neutralisation of residual sludge with carbonate, measurement of oxygen and inflammable gases at various points) were properly carried out. At the start of the operation, a deflagration occurred inside the tank. Casualties include one death and two cases of serious injury. The tank was partly destroyed. The explosion occurred due to the presence of hydrogen (100 g) in a dead area where no measurements were taken. The hydrogen resulted from the corrosion of the iron tank under the action of sulphuric acid.

ARIA 177 - February 2nd, 1989 - 60 - VILLERS-SAINT-PAUL

20.14 - Manufacturing of other basic organic chemical products

An explosion was caused by welding work carried out by a subcontracted firm on a 1,000-m³ benzene tank, with a toll of 1 death and 2 injured. The tank was lifted and ejected outside of the facility. No damage was observed beyond the site boundary. A judicial investigation was carried out to determine the exact circumstances of this accident.

ARIA 535 - November 28th, 1988 - UNITED STATES - KANSAS CITY - MISSOURI

42.2 - Construction of utility networks and lines

An arson fire and a 15-tonne explosion of ammonium nitrate occurred on a highway worksite. This first explosion was followed by a second one that blasted 7 tonnes of the same product ; 6 fire-fighters were reported missing, and another person was injured. Window panes were shattered in a radius of 15 km.

ARIA 1960 - May 21st, 1990 - 06 - GRASSE

20.42 - Manufacturing of perfumes and cosmetics

In a perfumery producing food flavouring products, an explosion occurred on a 25,000-liter tank containing ethyl alcohol, causing 1 death and 2 injuries. The plant had to be evacuated. Welding work was found to be the source of this accident.

ARIA 4869 - November 23rd, 1993 - 77 - FRESNES-SUR-MARNE

06.10 - Crude oil extraction

A series of explosions detonated and a fire broke out in a crude oil storage facility connected with a production well (11 m³/day at 60% water, 12 Nm³/tonne of gas). Three of the five 37.5-m³ capacity tanks exploded, 2 of which were blown 10 m away from the retention basin. Welding work undertaken by a local firm and performed without any written guidelines provided for the partially drained tanks that had not been degassed were responsible for this loss. One of the technicians was ejected 30 m and died on the spot, while a second was seriously injured (issuance of a 2-month work stop order). An employee working at a neighbouring quarry who came to offer assistance was slightly hurt. The 23.3 m³ of crude remaining in the separation tank were extinguished within 45 minutes by a response team of 70 fire-fighters. No hot work permit had ever been issued.

ARIA 5009 - October 29th, 1987 - 44 - NANTES

46.75 - Wholesale of chemical products

At a warehouse storing unknown contents, the self-sustaining decomposition of a stockpile of 850 tonnes of fertiliser NPK 15-8-22 delivered five days earlier caused the formation of a cloud 10 km long heading westward ; in this cloud, the presence of nitric acid and chlorine were detected.

The ORSEC plan for dealing with crises was activated; 200 fire-fighters, 627 police officers , 489 gendarme officers, 356 soldiers, 200 emergency responders and over 1,000 municipal employees were mobilised. An extensive evacuation plan spanning 7 municipalities located downwind of the warehouse was implemented. The incident was eventually controlled after 7 hours of emergency intervention.

The human toll amounted to 3 intoxicated employees, one of whom was placed in 24-hour observation at the hospital. Even though the overall evacuation measure applied to a population of 70,000, the actual number of individuals moved for a period of 9 hours during the crisis was evaluated at 38,000. The LOIRE River was only minimally polluted considering the widespread dilution of fire-fighting water.

As a result of both their transport conditions (in the hold of a ship that had previously stored wheat) and storage conditions (on a bed of sawdust), the fertilisers responsible for this accident were placed in close contact with organic matter, whose concentration at certain spots could have been quite high. Moreover, the site's obsolete electrical installation was partially to blame. The combustion zone began at a point directly aligned with the electrical cables that were dangling underneath the aboveground system for handling stored substances; the cut ends of these cables were probably buried in the mass of fertiliser. Under these conditions, ignition was likely initiated in the depths of the fertiliser pile, immediately adjacent to both the mass contaminated by sawdust and the buried electrical conductors. The fire then spread by means of self-sustaining decomposition of the fertilisers.

This accident still would not have reached such proportions had an efficient response been organised as of the initial detection of heat accumulation.

ARIA 5232 - May 3rd, 1994 - 31 - PORTET-SUR-GARONNE

42.13 - Bridge and tunnel construction

In a bituminous materials depot run by the BTP company and comprising 17 tanks, one of which contained hydrochloric acid, the vapour space of a vertical container filled to half its "cut-back 0/1" capacity (i.e. 18 tonnes of liquefied bitumen with 40% kerosene / flash point < 55℃) exploded around 2:30 pm, during the installation of walkways and guardrails between the tanks. The container was thrust some 20 metres and the 2 employees, who were already at the scene with a trimming machine close to the tank vent, died after being thrown a 30-m distance. The liquefied bitumen spread causing a fire and, less than 5 minutes later, the explosion of an empty, non-degassed bitumen container that wound up on the roof of a depot building some 10 metres away. Traffic was halted on the adjacent street leading to a shopping centre. Local residents and customers of a nearby shop, as well as all bystanders, were evacuated. The fire also ignited a row of trees planted on the property line; the emergency response team's quick arrival on the scene enabled containing and extinguishing the blaze.

The two containers broke at the level of the shell / bottom interface. The HCl storage capacity melted when exposed to the effect of heat ; moreover, 12 other tanks and the roof of the adjacent production unit were damaged. 7 company vehicles were destroyed. The retention basins were also extensively damaged. Total property loss was valued at 5 million francs.

During its investigation, the classified facilities inspection authority found that the operating instructions posted near the depot made no mention of prohibiting presence in the vicinity of any installation with devices capable of generating sparks or hotspots, and moreover that no risk analysis had been conducted prior to these works. Instructions were only being transmitted verbally, and lastly the site operator was unfamiliar with the combustibility characteristics of "cut-back 0/1", which is a Category 1 combustible liquid.

The initial inflammation was most likely triggered by a spark or hotspot during onsite works, which then ignited a vapour space outside the "cut-back 0/1" tank. The resulting vapours were able to "form" either at the end of the 6-m long hose set into place by workers to redirect vapours to the bottom of the container, or at the hose-vent junction (had the hose not been perfectly sealed), or at a tank cover opening designed for tank instrumentation (level measurement cable). After ignition of the vapours in an unconfined space, the flame penetrated into the tank causing the explosion and ejecting the tank.

Subsequent to the accident, the site operator proceeded by : installing a new depot with a storage capacity of less than 150 tonnes of emulsion, published a safety manual for nationwide dissemination, and organised a safety training course for site personnel. The installation was definitively closed on October 5th, 2007.

ARIA 6268 - December 13th, 1994 - UNITED STATES - PORT NEAL

20.15 - Manufacturing of nitrogenous products and fertilisers

An explosion occurred at 6:10 am inside an ammonium nitrate production unit (employing 119). A missile projectile during the explosion tore a 15-cm opening in a 3,800-m³ ammonia storage facility, producing a leak flowing out at a rate of 30 kg/s. The plant's external emergency plan was activated. Within a radius of 30 km around the site, some 2,500 residents were evacuated until the evening, following dispersion of an ammonia cloud reported to have spread as far as 15 km. The human toll came to 4 deaths, all plant personnel, and 18 injured (2 among the general public outside the plant). The explosion damaged dwellings and other buildings beyond the site boundary. A high-voltage power line crossing the state of Missouri was also affected, and electricity supply service to a neighbouring state had to be cut for awhile.

ARIA 8781 - October 18th, 1982 - 57 - METZ

11.06 - Malt production

An explosion occurred at 2:15 pm inside the materials handling tower of a silo located at a malt house during repairs of the facility's slabs and installation of a dust removal system, performed by 3 subcontracted employees. The filling ratio of silo cells was set at 12,000 tonnes compared with a theoretical capacity of 15,000 tonnes. A second more powerful explosion was felt a few seconds later, causing the tower to collapse along with 8 of the 14 cells containing barley and malt. Flames could be seen at various spots inside the silo boundary; 12 workers, including malt house personnel, subcontractor employees and lorry drivers (perhaps clients) were killed and buried under the rubble and debris; three others sustained injuries, one of whom was in serious condition. Considerable rescue efforts were deployed in the hope of finding survivors (a response team of 600 in all were dispatched to the site, including canine units and two cranes able to lift 150 and 300 tonnes, respectively). The instability of residual structures plus the tremendous pile of concrete rubble and spare equipment covered by grain strewn by the explosions severely complicated this rescue effort; the last victim was not removed from under the debris until 5 days later. Grain combustion raged another several days over the upper part of the cells that had not collapsed. Property damage, confined to the silo and its immediate surroundings over a distance approximately equal to the height of the installations, was assessed at 70 million francs (1982 currency value). The barley and malt debris disposed at the dumpsite of a former gravel pit wound up polluting the MOSELLE River alluvial fan for 2 years within a water extraction zone.

The cause and exact sequence of the explosions could not be precisely determined. The most likely hypothesis is that an initial explosion in the tower generated by the combination of an ignition source introduced during the works (or a careless smoker) and an explosive atmosphere caused dust to scatter inside the facility, leading to a second explosion throughout the tower and extending into the upper gallery and spaces between cells, where the collapses were eventually observed (outer row cells of the handling tower). The investigation also indicated the site's major dust accumulation problem, along with inadequate technical equipment (a complex dust removal system lacking efficiency features, absence of vents, etc.), organisational deficiencies (no practice of circulating memoranda relative to installation safety, no written instructions for carrying out works, no hot work permitting procedure) and, lastly, the workforce's general underestimation of the fire and explosion risks.

ARIA 11145 - August 30th, 1972 - AUSTRALIA - TAROOM

49.41 - Road freight transport

A small electrical fire broke out inside the engine of a lorry transporting 18.5 tonnes of ammonium nitrate, packaged into 510 polyethylene bags and intended for explosives manufacturing. The vehicle's cabling proved to be faulty. The fire reached the lorry's trailer, where 7 tonnes of ammonium nitrate melted and spilled onto the road over a distance of 110 m. More than ten minutes after the fire broke out, the load being hauled exploded, killing the lorry driver and 2 neighbours in the vicinity who had shown up to offer assistance. Their bodies were thrown some 30 m. Lorry debris could be found as far as 2 km from the scene. A crater 10 m in diameter and 1 m deep was formed. This explosion could be explained by the liquefied state of the nitrate and its contamination by the carbon black generated from combustion of the lorry's tyres.

ARIA 11345 - March 12th, 1997 - ITALY - PESCHIERA DEL GARDA
37.00 - Wastewater collection and treatment
At a municipal wastewater treatment plant, an explosion occurred while repair works were underway inside a concrete silo dedicated to biogas fermentation and production. Residue from gas and welding operations were at the origin of this accident. Two workers were ejected from the silo and died on the spot, while a third fell to the bottom of the structure and sustained serious injuries. The silo roof was also blown off.

ARIA 12038 - December 24th, 1986 - 13 - CHATEAUNEUF-LES-MARTIGUES
19.20 - Oil refining
During a welding operation, an explosion occurred on a tank containing heavy fuel oil killing one and seriously injuring another.

ARIA 12271 - April 15th, 1947 - UNITED STATES - TEXAS CITY
50.20 - Maritime and coastal freight transport
At a port facility, a cargo vessel already containing miscellaneous materials was loaded with fertilisers (ammonium nitrate serving as the base ingredient). The product, packaged into 45 kg bags, resembled small brown grains (composition : 32.5% nitrogen, 4%-5% mineral load, and 1% a coating mix made from Vaseline and resin). During the loading phase, 1,400 tonnes were placed in Hold 2 and another 800 tonnes in Hold 4. The next morning at 8 am, after smoke was detected in Hold 4, a small quantity of water was discharged onto the presumed firebox before reclosing the hold with restricted ventilation (by means of blocking orifices). The situation worsened, as pressure forced open the orifices through which a reddish orange smoke was escaping. At 9 am, the hull of the ship was already burning hot. A very violent explosion ensued at 9:12 am. Projectiles, quite large in some cases, were found far from the accident site (e.g. a 1.5-tonne anchor was blasted into a refinery more than 3 km away!). The explosion caused a tidal wave on shore. An adjacent ship, loaded with sulphur and ammonium nitrate (961 tonnes) also caught on fire. The inflamed vessel could be towed around 50 m away from the coastline out to sea, where at 1 am it exploded. The accident's toll was approximated at 581 dead and 3,500 injured. Damage to the port and neighbouring dwellings was extremely severe. Glass panes far and wide were shattered. Fuel reserves ignited following the second explosion, as did a number of silos. Five days after the disaster, fires were still burning out of control in the city.

ARIA 13357 - May 19th, 1998 - 79 - PAMPROUX
10.9 - Manufacturing of animal feed
In a cattle feed factory, welding operations on the roof of a 140-tonne capacity storage cell that was holding 40 tonnes of rape oil meal were the source of an explosion occurring in the vapour space of the enclosure. The metal roof as well as all roofs made of everite tiles on the adjacent buildings were blown off. The welder, who was employed by a subcontractor, was slightly hurt. Total damages were estimated at 30,000 francs. The terms of the hot work permit granted for this operation lacked sufficient precision. Administrative authorities logged the event.

ARIA 14373 - September 21st, 1921 - GERMANY - OPPAU
20.15 - Manufacturing of nitrogenous products and fertilisers
At a chemical plant, an explosion destroyed a building storing 4,500 tonnes of a 50-50 composition of ammonium sulphate-nitrate, forming a crater 90 m wide, 125 m long and 20 m deep. Shortly thereafter, a series of fires broke out on the facilities, caused by a domino effect, amidst other explosions of lesser intensity. Heard more than 275 km away, the detonation created panic among the local population. A dark green cloud blanketed the sky over the region, and the telegraph and telecommunications infrastructure was destroyed. The extent of damage reached several tens of km from the accident site.
The result of this disaster was dramatic: 561 dead, 1,952 injured and over 7,500 left homeless. Nearly 80% of the buildings in the city of Oppau were levelled ; considerable destruction was also observed in the towns of Ludwigschafen and Mannheim. In Heidelberg, about 30 km from Oppau, traffic was prohibited due to the large-scale presence of glass debris on road pavements. The magnitude of property damage and great numbers of victims complicated the task of emergency services. During these troubled times, politically, socially and economically speaking, it would take 3 years to remove all remnants of the accident.
The difficult investigation subsequently launched lasted more than 2 years. A report published in 1925 ultimately established that the accident occurred following a controlled blast carried out in the ammonium sulphate-nitrate stockpile for the purpose of disaggregating fertilisers clumped into a mass (a hygroscopic mix). Just a few months before the explosion, the manufacturing process had undergone modification in order to yield dryer fertilisers (2% humidity instead of 3%-4%), with a lower apparent nitrate density, yet making the final product more explosive. Moreover, the composition of the 4,500-tonne pile of ammonium sulphate-nitrate mix was likely to have been quite heterogeneous, with some zones containing a higher concentration of ammonium nitrate. The explosiveness of such a mix actually increases rather considerably should the proportion of ammonium nitrate rise from 50% to 60%. So when the blast was detonated, an enriched ammonium nitrate mix could ignite, causing the neighbouring portions of mix with a 50/50 split to explode; the detonation did not immediately spread to the entire stockpile, limiting the explosion to just 10% of the total mass (i.e. higher-density zones were spared).
During preliminary testing conducted in 1919 before production start-up, the operator had concluded that mixes of ammonium sulphate / nitrate at concentrations of less than 60% ammonium nitrate were non-explosive. These fertilisers were subsequently treated as a non-hazardous material. When the industrial process was modified in 1921, no additional tests were performed on the resultant mix. This accident highlights that a modification with apparently minor consequences on the end product properties can indeed substantially increase sensitivity to triggering an explosion.

ARIA 14732 - July 28th, 1947 - 29 - BREST
50.20 - Maritime and coastal freight transport
A docked Norwegian ship held a total of 3,133 tonnes of bagged ammonium nitrate grains in cargo holds 1, 3 and 5 ; in the deck cargo area above these holds, combustible or inflammable substances were being stored, including : fuel oil, paints, lubricants, rubber, polystyrene, paraffin, methyl ethyl ketone, and butyl alcohol. Around 12:30 pm, a white smoke turned yellow in exiting a venting tube from Hold 3. The vapour extinction system was needlessly activated (introducing heat and oxygen present in the nitrate). Red smoke was seen in the exhaust from the hold's other venting tubes. A low rumble could be heard. Emergency workers opened the vibrating access panel. The fire was growing in intensity, with explosions ejecting cargo onto the ship's deck or in the water. Flames reached

some warehouses along the dock (triggering a domino effect). A tugboat towed the crippled ship away from the port, though with its superstructures already ablaze, the vessel ran aground at 2 pm on a bank located too close to the city. At 5 pm, the fire was out of control, as barrels of oil stored in Hold 2 ignited and flames began spewing from Hold 1, which was storing 739 tonnes of nitrate. The boat was now adrift; an explosion at 5:25 pm killed 26, while hundreds of others were hurt. A 5-m wave engulfed the docks, and the city endured a bombardment of material projectiles, causing major damage (the fire spread to a gas plant and oil depots, and elsewhere). Glass panes were shattered up to 70 km from the blast, and ironwork was found as far as 22 km away. Paraffin and other molten materials had seeped into the nitrate stock.

ARIA 16467 - August 10th, 1999 - 76 - FECAMP

20.17 - Fabrication of synthetic rubber

At a rubber factory, an explosion occurred inside a lubricant container filled with 18 tonnes of tri-(nonylphenyl) phosphite (TNPP or TNPA). This tank was typically stirred and maintained at 45°C ; moreover, the heating circuit routed to the container had broken down 7 days earlier. With the polluted TNPP scheduled for disposal, the accident occurred during a sawing operation to remove the walkway interfering with the manhole opening. The TNPP substance underwent hydrolysis in contact with water leaking via the broken coil ; the resultant phosphoric acid corroding the steel on the container caused hydrogen to form. The relatively slow hydrolysis reaction was no doubt catalysed by metal particles (rust, etc.). A technician was seriously injured due to a fall. The new installation would obviously be ventilated and protected from rainfall or any other potential water intake. A heating belt (with T_{max} < T°of TNPP degradation) replaced the coil, and a posted instruction reminded workers of the product's sensitivity to water.

ARIA 17972 - April 29th, 1942 - BELGIUM - TESSENDERLO

YY.YY - Undetermined activity

150 tonnes of ammonium nitrate contained in a silo exploded, causing several hundred deaths and major property damage. The explosion was caused by a blast detonated with explosives, which was part of customary practice for masses of aggregated nitrate. Such a practice using explosives had in fact been commonplace at this plant for the purpose of disaggregating raw potassium chloride; on the day of the accident, an unsuspecting worker thought the same technique could be applied to ammonium nitrate.

ARIA 17974 - July 26th, 1921 - POLAND - KNUROW (KRIEWALD)

20.51 - Explosives manufacturing

In a company whose activity consisted of producing a range of products including explosives, 30 tonnes of ammonium nitrate exploded, following disaggregation of a bulk nitrate load by means of blasting. A funnel-shaped crater 20 m in diameter was dug into the ground. The human toll came to 19 deaths.

ARIA 21241 - September 4th, 2001 - 35 - MONTAUBAN

10.91 - Manufacturing of farm animal feed

In a factory specialised in animal feed, an explosion followed by a fire occurred in one of the silos for storing crushed raw materials, where an employee with a subcontracted firm was performing an arc welding operation. The full set of installations were shut down as an emergency measure, and the seriously injured worker was evacuated from the site. The continuation of filling operations on the other containers had caused dust to spill into the silo undergoing repairs via a rotary drum connected to the network of silo feed pipes. The air-dust mix exploded in contact with the welder's electric arc, which was included in the tasks assigned to the subcontractor. The classified facilities inspector's analysis of the prevention plan plus the nature of operations conducted preliminary to these works revealed, on the one hand, noncompliance with several procedural steps that had proven inadequate ; on the other hand were organisational shortfalls or lapses relative to the control, knowledge and execution of these operations. More specifically, the hot work permit submitted by the technician performing these safety-related works eliminated all 2nd-level controls. The site operator was issued an injunction to revise facility procedures.

ARIA 21737 - July 17th, 2001 - UNITED STATES - DELAWARE CITY

19.20 - Oil refining

While a subcontractor was performing hot work on the renovation of a walkway placed above Tank 396 at an oil refinery, Tank 393, containing a mix of sulphuric acid (H_2SO_4) and so-called "spent" H_2SO_4 hydrocarbons, exploded around 1:30 pm. The affected tank rose and then collapsed towards the north, causing the walkway to fall and leaching 1,000 m³ of H_2SO_4. The force of the explosion damaged Tank 396, which in turn released 1,332 m³ of H_2SO_4. The acid, whose surface was on fire by the burning of inflammable materials, overflowed the retention facilities and wastewater network, before spreading into the site's aisles. The operator estimated that 375 m³ spilled into the DELAWARE River, killing some 2,500 fish and 250 crabs. The American Environmental Protection Agency (EPA) estimated the total volume of H_2SO_4 lost at 4,164 m³.

The toll stood at 1 death and 8 injured by eye and lung burns as well as nausea from the vapours. Due to the acid contamination and quantities remaining in the intact tanks, emergency response teams were not able to enter the zone until August 17th, i.e. 32 days after the accident. The search for the dead worker's body was called off on September 18th. The Federal agency assigned to report on chemical accidents (Chemical Safety Board, CSB) conducted an investigation.

The Board's final report pointed to several areas of negligence. Tank 393 had been converted from storing "clean" H_2SO_4 to the "spent" category in 2000 without any precautions taken. As opposed to "clean" H_2SO_4, the "spent" form of H_2SO_4 contains hydrocarbons, and inflammable vapours are capable of forming, thus requiring a CO_2 inerting treatment. On Tank 393, this system consisted of a simple rubber pipe inserted into the tank and delivering only a small flow of CO_2. The tank also displayed a number of holes caused by corrosion, through which inflammable vapours were able to escape; moreover, the most recent inspection dated back to 1996.

The refinery owner was aware of these shortcomings, yet nonetheless issued a hot work permit. Subcontractors were not informed of the presence of such vapours and only initiated gas detection as of the morning of the explosion, upon arrival at the site. They should have repeated controls at the beginning of the afternoon, especially given that the temperature had already risen. Also, they had not yet installed protection against flying sparks, in failing to comply with permit specifications.

Both the federal government and the state of Delaware filed lawsuits. The operator paid €370,000 in pollution cleanup measures, another €6 million on safety upgrades, €32.4 million for bodily injuries, €130,000 to reimburse public rescue services and €10.2 million in fines for ecological violation.

ARIA 22278 - 10/10/1985 - ITALIE - RIPALTA ARPINIA

20.15 – Manufacture of nitrogenous products and fertilizers

In a fertilizer production plant, a sulphuric acid (H2SO4) container exploded while two technicians were performing oxyacetylene cutting operations in the vicinity to remove plates fixed by nuts. The two technicians died in the explosion. The capacity was projected across the workshop and destroyed two other H2SO4 containers whose contents spilled onto a retention tank. The acidic cloud evaporated from the spill and dissipated into the atmosphere without any effects on the residents. Sodium carbonate was sprayed to neutralise the acid and avoid corrosion of the 'ammonia pipes passing though the retention area. The explosion resulted from the ignition of the hydrogen accumulated in the tank by the oxyacetylene flame. Hydrogen was formed by the corrosion of the steel tank by the sulphuric acid due to insufficient maintenance of the storage equipment.

ARIA 23705 - January 1st, 1989 - 76 - GONFREVILLE-L'ORCHER

20.16 - Manufacturing of basic plastics

In a chemical plant, a hydrogen (H_2) explosion occurred in an empty 100-m³ tank of sulphuric acid (H_2SO_4). Built in 1973, this storage container was lifted 5 cm, yet its anchorages were able to resist the blast. The tank was repaired by installing an angle bracket type of reinforcement at the level of the bottom/shell junction and replacing the 4 threaded anchorage pins. This accident could not be accurately dated. A similar accident in 2009 would once again implicate this same tank (ARIA 36628).

ARIA 24977 - 02/07/2003 - 91 - MORSANG-SUR-SEINE

37.00 - Wastewater collection and treatment

Inside a water treatment plant, an exothermic reaction caused an explosion on a retention basin and the ensuing release of acid vapours. A 50-m safety perimeter was established around the plant, with the closest residences situated 300 m away. Some fifty firefighters identified the leak source; the gases formed could escape via the ventilation system connected to the premises where the explosion first happened. The products contained in the destroyed tank were recovered in the surrounding retention basin. They were then pumped and discharged to an external treatment facility. The accident exerted no impact on water production, which could proceed using the two intact remaining trenches and moreover no discharge was released into the natural environment. The explosion occurred within a steel tank located in the basement of the site's storage building ; this tank served as temporary offset retention for the storage of sulphuric acid (H2SO4) during restoration of the site's normal retention capacity. The accident might have been due either to the sudden arrival of acid into the tank, thereby triggering a violent reaction with the steel followed by hydrogen production, or to a violent reaction caused by a mix of H2SO4 with a product contained in the basin or with a product discarded into the drain hole by a third party.

ARIA 25087 - July 4th, 2003 - UNITED STATES - FRAMINGHAM

42.11 - Road and highway construction

An explosion occurred at a factory specialised in manufacturing tar, on an asphalt tank. An employee was welding with a blowtorch and wound up being ejected some 10 metres high ; he was seriously hurt and hospitalised in critical condition. A second employee suffered burns and was also taken to hospital, as was a fire-fighter distressed by the heat. The explosion shook several homes and plants in the vicinity. More than 20 fire-fighters were needed to control the incident after 1 hour of battling the blaze by spraying foam.

ARIA 27273 - June 8th, 2004 - JAPAN - AKITA

20.20 - Manufacturing of pesticides and other agrochemical products

At an agrochemical plant, an explosion occurred near a drained hydrofluoric acid tank as 4 employees were welding on adjacent pipelines. One of the technicians died as a result of his burns, while the other 3 sustained injuries. According to the operator, air pollution measurements recorded around the plant did not indicate the presence of any toxic products, and moreover the impacts on both the environment and local residents would be minimal. An investigation was launched to determine this accident's causes. The presence of hydrogen might have been the source. Except for the unit already shut down for maintenance, plant activity was not interrupted.

ARIA 28569 - October 26th, 2004 - 47 - LAVARDAC

33.20 - Installation of industrial machines and facilities

An explosion occurred in a facility dedicated to the renovation and maintenance of boilers during repair work on one such boiler. A technician had previously de-scaled the device using hydrochloric acid before proceeding with the neutralisation step with soda and draining the passive acid introduced. The significant scaling on the boiler required a second acid injection, followed by welding work, but this time without draining the boiler. Hydrogen emitted by a metal + acid reaction was the cause of this accident. An employee wound up in hospital in a coma. Labour inspection authorities noted that operating conditions were not favourable towards environmental protection, i.e. failure to control discharge pH, absence of written procedures.

ARIA 29864 - May 21st, 2005 - 38 - CHAMPAGNIER

20.13 - Manufacturing of other basic inorganic chemical products

A pipeline used to transport gaseous chlorine (Cl_2) exploded between a chemical platform (run by the producer) and an elastomer manufacturing site (user).

The pipeline, built in 1961 for the transport of hydrochloric acid (HCl), had been operated since 1986 for transferring deoxygenated and dried Cl_2. 200 mm in diameter and 3,600 m long, made of painted steel, heat-insulated and outlined over the upper external part by a heating tube via the skin effect, this pipeline was being operated at 4 bar relative pressure and 30℃. As of the previou s day, production had been shut down for a 10-day maintenance period, bringing the pressure inside this chlorine pipeline down to 0.25 bar.

The explosion occurred outside the user's site 150 m from the delivery point; the pipeline was ruptured in 4 spots and showed traces of internal shock waves over a 70-m length. The explosion produced no victims, despite considerable pipe debris being strewn over a 150-m radius. The quantity of Cl_2 emitted into the environment was evaluated at 475 kg. The damage identified (spiral rupture, pressure wave, etc.) characterised the detonation power of the explosion. The physical impacts were significant on the 4 other pipelines (100-mm diameter) of the aboveground rack: 2 nitrogen pipes (13 bar, 2,000-3,000 m³/hr) were deformed, yet remained sealed. Their pressure was brought down to 10 bar, the damaged oxygen pipe (10 bar) had been

drained, and the last disused pipe contained nitrogen (N_2) at atmospheric pressure.
An H_2 / Cl_2 explosion caused the accident. The formation of H_2 (20%) can be explained by a combination of several elements: accidental introduction of humidity into the pipe during a previous maintenance operation, leading to hydration of the ferric chloride present; a crystalline phase change in the deposit (according to the operator, due to excessive heating of the pipe, i.e. 80°to 90℃) and thus facilitating attack of the st eel (by hypochloric acid) as well as H_2 formation; heating resulting from a drop in electrical supply of a temperature sensor, following a cable break at the user's site during inappropriate handling of one of the structure's protective slabs 3 days prior.
The proportion of hydrogen (20%) released into the gaseous Cl_2 contained in the insulated pipeline at each end, under low pressure (0.25 bar), gave rise to an explosive mix that a very small amount of energy could trigger (i.e. roughly 10 micro-Joules would be sufficient for ignition).
The operator cleaned the interior of the structure (2.5 to 3 tonnes of mineral and organic residue were extracted) and made plans to: insert temperature probes every 500 m along the length with both low and high safety levels ; revise and secure the electrical layout; and perform regular endoscopic controls.

ARIA 31082 - 26/11/2005 - 69 - PIERRE-BENITE
20.13 - Manufacture of other basic inorganic chemicals
An explosion occurred in a chemical site causing the cover of a 99.2% sulphuric acid tank (filled to 300 t of its total 1500 tonne capacity) to open partially. The cover opened along the circumference of the tank at the dome / shell fitting. The POI (internal emergency plan) was triggered. No emission or leak was reported except for the emission of fumarole at the opening. No environmental or human consequences were reported. Material damage was limited to the equipment located above the tank (acid supply pipes, air pipe going to the dryer, walkway, steam pipe, etc.). The presence of hydrogen (a few dozen grams), generated by the corrosion of steel by the weak acid was responsible for the explosion. The accident was further to a series of incidents in the unit manufacturing H2SO4 through the absorption of SO3 in packed columns: two successive piercing incidents of the water/acid heat exchangers of the transfer columns on the day before the accident caused an around 85% titer to flow into the acid storage tank (1st incident), followed by acid with a practically zero titer (2nd incident). Before the explosion the tank contained a heterogeneous mixture with a weaker surface titer. The explosion occurred 1 hour and 15 minutes after the tank had been agitated. The ignition of H2 (requires very low energy) was probably electrostatic. The two piercing incidents of the heat exchanger were due to a phenomenon of corrosion by pitting near the seam welds on the side of the cooling water. Modification of the anti-legionella biocide treatment since the previous year may have favoured the phenomena of corrosion by pitting. The use of liquid bleach instead of bromine greatly increased the oxidising power of water and thus lowered the starting temperature of corrosion pitting. Decreasing the speed of passage of water (on account of the drop in the workshop activity for a long period) contributed to increasing the temperature of the medium, is another aggravating factor for the accident. The measures taken include water treatment (temporary use of a non-oxidising biocide and study of a continuous chlorine-bromine treatment), detection of any abnormal arrival of water in the process (temperature detector with alarm, titrators), operating procedures (prohibition on adding weak acids to storage tanks).

ARIA 33574 - June 5th, 2006 - UNITED STATES - RALEIGH
46.71 - Wholesale of fuels and ancillary products
An explosion occurred during installation of a connection between 2 hydrocarbon storage tanks in an oil field depot. During welding, sparks ignited the hydrocarbon vapours escaping from a nearby open pipe.
Subcontracted personnel were assigned works on the 4 interconnected tanks : contents of Tank 4 spilled into Tank 3, whose overflow led to Tank 2 and then to number 1. Workers removed the hatch at the base of the 4th tank to drain the crude oil residue contained inside. After rinsing with water, they allowed the hydrocarbon vapours to evaporate for several days. On the day of the accident, one of the workers inserted a blowtorch to place the oxy-acetylene weld inside the hatch, then in the vent on the opposite side of Tank 4 in order to verify the absence of combustible vapour. The 4 workers proceeded by climbing a ladder placed on Tanks 3 and 4. Shortly after they began their tasks, fire broke out at one end of the pipeline at Tank 3, then spread to Tank 2 via the overflow pipe, as the tanks exploded causing flames to jump over 15 m high. The covers of both these tanks were torn off, one landing 180 m away. The 3 workers who had climbed onto Tank 3 died and the 4th employee, who was attached by a harness, was seriously injured. A bystander called the local emergency services, and the police were also deployed to the scene.
The risk analysis revealed many instances of noncompliance with safety procedures during the hot work, despite the availability of technical guides. A gas detector should have been introduced, as use of a welding torch was extremely dangerous. The pipe open onto the adjacent tank should have been covered or insulated before initiating the works or, better yet, the combustible vapours should have been eliminated by cleaning Tanks 2 and 3. Moreover, the subcontractors should have assembled a scaffolding rather than a ladder that needed to be held in place by wedging against Tank 3. Also, the subcontractor had not established any safety procedures for its employees, while the depot operator failed to impose such procedures.
The operator planned to develop and implement a written set of procedures so as to guarantee safe working methods for both tank cleaning and aboveground hot work.

ARIA 34921 - May 2nd, 2007 - 03 - MONTLUCON
20.14 - Manufacturing of other basic organic chemical products
A blast erupted at a chemical plant during a synthesis operation involving sodium triacetoxyborohydride inside a 5,300-litre reactor. Around 5:30 pm, the technician observed that the acetic acid intake pipe was plugged. After opening the manhole with a wooden pole, the shop foreman dropped the stalactite of solidified acetic acid in the reactor: the resulting blast severely burned the foreman's face.The blast was caused by inflammation of the hydrogen produced from the dropped quantity of acetic acid, as the maximum amount of acetic acid introduced into the reactor was estimated by the operator at 3 kg, which led to the formation of approx. 100 grams of hydrogen in this 5,300-liter reactor. The accident had no impact either on the environment or on other shop installations.

ARIA 35371 - October 19th, 2008 - UNITED STATES - LA RUE
06.10 - Crude oil extraction
Around 2:30 pm, an explosion occurred at a crude oil extraction facility killing the two employees who were carrying out welding work on top of a crude oil storage tank, which was connected to two adjacent tanks. The filling operation underway at one of the adjacent tanks caused inflammable vapours to move in the direction of the tank being welded via the breathing vent located beside the welders. The combustible cloud was ignited by welding sparks and then exploded. The investigation conducted by administrative authorities revealed that the workers (subcontractor's employees) had failed to measure the explosive potential both before and during

welding; moreover, no procedure had been adopted for hot work, nor were any jobsite controls in place for subcontractors. Lastly, the two subcontracted workers had not received any training in the risks associated with hot work.

ARIA 36561 - IC - July 27th, 2009 - 76 - GONFREVILLE-L'ORCHER
TOTAL PETROCHEMICALS FRANCE
20.16 - Manufacturing of basic plastics
At a SEVESO-rated plastics factory, fire broke out at 4:50 pm in a settling basin for hydrocarbon residue containing mainly sands, polyethylene and polypropylene pellets and heavy hydrocarbons (e.g. sewer clearing sludge), on a floor area of roughly 50 m². A thick black smoke was released and could be seen as far as the city of Le Havre. The internal emergency plan was activated, and in-house responders extinguished the blaze by 5 pm using foam, at which time the plan was lifted. The released heat flow did not reach the 2,500-m³ spherical butylene tank located 50 m from the basin, nor did it reach the 2 naphtha tanks 200-250 m away. Sparks originating from the structural work taking place on a nearby unit were the cause of this fire. A technician was cutting with a grinder (installing rebar for a future reinforced concrete wall) at a distance of 2 m from the settling basin. Following this fire, the site operator notified authorities from neighbouring towns as well as members of the Local Information and Consultation Committee.

ARIA 38415 - July 29th, 2008 - UNITED STATES - NC
17.12 - Paper and cardboard production
In a cardboard production facility, a maintenance operation was planned on the dome cover of a 25-m³ tank containing water and paper fibres. The operation was assigned to 3 employees and consisted of repairing a flange by performing a weld. An explosion occurred and ripped open the tank roof. All 3 workers were killed as a result of the traumatisms suffered ; two bodies were found at the foot of the tank. Another employee, who observed the event from a distance, was also hurt. An investigation was launched by the federal agency overseeing chemical accidents (CSB) ; their report indicated that anaerobic bacteria had proliferated in the tank containing fibre waste and wastewater, as well as in the water recycling system, due to the presence of organic waste. Site employees were not at all aware that the multiplication of anaerobic bacteria could produce combustible vapours, most likely hydrogen, and therefore did not measure the explosive potential in the tank before undertaking these works.

ARIA 38557 - June 10th, 2010 - ITALY - BRINDISI
21.10 - Manufacturing of basic pharmaceutical products
An explosion occurred around noon while welding was being conducted in a tank at a pharmaceutical products plant employing 240. The tank cover was ejected a few metres, killing a subcontracted worker, who in turn was thrown 50 m ; also, 3 employees were seriously injured (2 of whom were subcontractor employees) and 1 was slightly injured (also subcontracted). The fire-fighting crew was able to extinguish the fire ; the local municipality, along with the provincial government and Environmental Protection Agency, were informed of the accident. The operator issued 2 press releases.
Site activity was suspended, and a judicial investigation conducted in order to determine the exact causes and circumstances surrounding the event, as well as the liabilities and eventual negligence. The subcontractor's legal representative and project manager, along with the plant director, were charged with involuntary homicide and inflicting serious injuries. According to the initial elements available, the tank might have contained process water and chloroform. The work permit on the tank had been signed by the Head of Safety. Moreover, investigators undertook a series of analyses to determine whether a substance capable of reacting and causing an explosion had not been introduced by mistake into the tank where works were taking place (perhaps not entirely empty?) ; other examinations were performed to verify whether the safety relief valve protecting the tank was obstructed or defective.

ARIA 38595 - March 31st, 2009 - UNITED STATES - ATWATER
10.31 - Transformation and preservation of potatoes
On the site of a company that was packaging sweet potatoes, 2 employees were using an acetylene blowpipe to remove a high-precision fitting from an older fuel oil tank for reuse on a new tank. During this operation, the tank exploded and seriously burned both workers over 30% to 50% of their bodies ; the two of them had to be transported by helicopter to a major burn centre.
The tank had not been cleaned or drained, and neither employee had used a gas detector. The company had not specified a procedure for work on hotspots, and no hot work permit had ever been issued. Moreover, many employees only spoke Spanish and had not received training on safety procedures and the use of gas detectors in their native language.

ARIA 38596 - October 7th, 2008 - UNITED STATES - KAPOLEI
52.10 - Warehousing and storage
On a site used to store miscellaneous products, a subcontractor was performing welding work on a walkway located above a 32,500-litre tank containing used oil. Sparks fell into and around the tank vent and ignited its contents. The tank exploded and was thrust 10 m; a fire ensued. The welder, thrown 37 m by the blast, died and 3 other employees were injured. An investigation was initiated by the fire department. It turns out that the subcontracted workers had never been awarded a hot work permit to perform welding in this zone. The subcontracting firm declared having the impression that this type of work was authorised and moreover that the operator had already checked for gas before they arrived onsite.

ARIA 38599 - May 12th, 2009 - UNITED STATES - GARNER
52.10 - Warehousing and storage
Around 2:30 pm, subcontractors were creating an opening using a blowtorch on the mobile roof of a 10,000-m³ gasoline tank for the purpose of installing a gauge. The heat ignited vapours within the tank, which then exploded killing all 3 subcontracted employees.
An investigation revealed that the subcontractor had received from the site operator an authorisation to work in a confined space as well as a hot work permit. Moreover, gas measurements were recorded at 7 am. Yet nothing indicated that gas detection was repeated upon returning from lunch or before resuming the job.

ARIA 38600 - February 16th, 2009 - UNITED STATES - BOARDMAN

10.31 - Transformation and preservation of potatoes

A subcontracted welder was patching a 3 cm x 1.3 cm crack found at the base of a clarifier for potato washing water within a food processing plant. An explosion occurred and led to collapse of the internal structure, killing the employee working inside. The federal agency dealing with chemical accidents (CSB) initiated an investigation. It turns out that approx. 35 cm of wastewater had accumulated in the space underneath the tank skirt and bacterial degradation had caused combustible gas to form. The investigation also revealed that gas detection had been performed, but only at the tank entrance and not at the level of the crack to be patched. In addition, the personnel had not been appropriately trained in the use of detectors, and no hot work permit had ever been granted.

ARIA 39076 - September 15th, 2010 - FINLAND - OULU

20.59 - Manufacturing of other chemical products n.c.e. (not classified elsewhere)

In a pine and terebenthine oil refinery, a violent explosion occurred around 8:30 am during welding operations on a 150-m³ tank of terebenthine filled with water. A subcontracted employee was killed on the spot and 3 others injured : one was seriously hurt and required hospitalisation. Several ambulances were dispatched to the site.

Outside of the tank directly implicated in this accident, no other damage was observed; the refinery resumed activity on the same day. This storage tank was being washed and repaired to be placed back into service. The initial elements of the investigation indicated that a welding spark was the cause of the explosion. Local police conducted their own investigation for involuntary manslaughter and injury.