

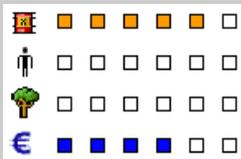


## Domino effects

### ③ Ignition of an ethylene leak on a pipeline

ARIA 35672 - 17/03/2008 - GERMANY - KÖLN

20.16 – Manufacture of basic plastics



During maintenance operations, there was a leak at the tie-in of an ethylene pipeline connecting several plants in the region and the one connecting a chemical plant manufacturing basic plastics. The valves were closed but the ethylene that stopped leaking from the pipe section ignited. After some time, the heat emitted caused the fire to spread and destroy a by-pass valve leaving 11 km of the pipeline (distance until the next isolating valve) non isolated.

Ethylene contained in this 11 km section of the pipeline was at 80 atmospheres. A massive 30 m high flame was observed. The intense heat flow effected an aluminium tank containing acrylonitrile that was 10 m away. Even though the container was protected by a concrete wall, the acrylonitrile boiled and evaporated. Given the temperature, the container itself was “burning” and risked collapse. The fire-fighting operations became complicated but the blaze was brought under control in the end. However, half of the container was burnt. Material damage was significant but no casualties were reported.

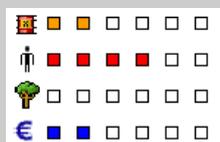
Further to this accident, two expertises put forward several recommendations on improving the safety of pipeline tie-ins, as well as on the minimum distance to be maintained between inflammable gas pipelines and tanks containing inflammable liquids. The local authorities implemented an inspection schedule for transport pipelines of similar configuration implanted near SEVESO sites. The possible application of these recommendations may lead to new inspections, updating of safety reports and adaptations to meet new requirements.



## ④ Ignition of a hydrogen leak on a pipeline

**ARIA 35860 - 12/10/2007 – NETHERLANDS - BINNENMAAS**

49.50 – Pipeline transport



A fire broke out in a pipeline passageway bringing together several underground pipes carrying hazardous products such as hydrogen, kerosene, ethylene oxide, etc. The blaze was brought under control in a few minutes given the size of the leakage. The incident had no serious consequences but was nevertheless considered serious due to the presence of the other pipelines in the passageway including some carrying toxic gases.

According to the inspection department in question, hydrogen ( $H_2$ ) in an underground pipeline was ignited by welding operations underway in the vicinity. A differential subsidence of the ground with a local deformation of the pipeline at the cathodic protection device was believed to be the source of the  $H_2$  leak. The sandy nature of the ground was conducive to the subsidence due to the presence of heavy equipment on the surface (drain pump, construction site vehicles, etc.) used during excavation operations carried out for laying a new kerosene pipeline. Even though the transportation of dangerous substances through this passageway is considered to be managed safely, some shortcomings were nevertheless identified. Calculations had to be made to identify the maximum acceptable load above such pipe networks and a more active supervision of pipelines was recommended.

## Domino effects

The two incidents of ethylene and hydrogen leak illustrate the dangers involved in transporting inflammable material through pipelines. Several accidents also involve toxic material, combustible fuel, environmentally hazardous substances etc. The ARIA database has recorded around ten such incidents with an impact depending on the fluid transported, its physico-chemical properties, the flow rate and pressure in question and its toxic or polluting effects.

In the event of a leak not igniting immediately when transporting inflammable material, the hazardous liquid or gas may spread to a wider area (ARIA 2257, 14689, 24548, 5371, etc.), through preferred paths (gutters, sewers, cracked grounds, etc.) before igniting or exploding upon contact with a hot point like the passage of a vehicle (ARIA 5817, 126, 3325). The wide spread dispersion of the inflammable material in liquid or gaseous form is a factor that is critical in determining the intensity of the effects especially when ignited later in time. Such accidents can be devastating and result in several victims (ARIA 27681). This point is crucial in defining the safety parameters relating to the emergency plans. Heat radiation can also ignite combustible matter stored in the vicinity and melt equipment like in the case of the first accident presented (ARIA 27723, 30005, etc.).

The shock wave or blast effect of an explosion, as well as projections of fragments impact nearby installations (ARIA 7128, 29864, 27516, etc.) but can also have a ripple effect far away from the leak site (ARIA 3325, 11649, 19380, etc.), specially when the inflammable cloud explodes upon contact with a hot point located several dozen or even hundred metres away from (ARIA 7128, 10173, ...) the leak site. Several cases of BLEVE involving toxic or inflammable liquefied gas containers result from pipeline fires (ARIA 6756, 7128, etc.).

Underground pipelines or “pipelines in drains” can be sources of severe pollution (ARIA 23839, 32818) including some rather insidious cases (weak flow rate over a long duration, etc.). Merging of pipes (pipe passages, racks, etc.) deserve special care due to their proximity with several other pipes transporting hazardous substances (ARIA 34176, 2<sup>nd</sup> accident presented).

The transportation of toxic material such as ammonia (ARIA 5371, etc.) or chlorine (ARIA 29864) also create a public hazard in the event of a leak as well as put at risk the safety of technicians likely to be incapable of safely continuing to operate or stop their facilities (risk of indirect ripple effects).

Corrosive substances are dangerous to a lesser extent but may spread to other more dangerous pipes in the vicinity (inflammable gas or liquid, toxic material, etc.). Water pipes especially with a wide diameter and high pressure (ARIA 16863, 34945, etc.) can cause significant damage by ripping or wetting the soil or even weakening the foundations.

The layout, indication and precise information on the exact location of the pipeline on updated maps, as well as inspection of surface markers of underground pipes are essential elements deserving special care especially in urban, peri-urban, agricultural or natural environments: ARIA 27723, 32818, etc.

Firstly pipes must be equipped with adequate mechanical, chemical and electric protection as they are exposed to several kinds of stress such as natural (landslides, lightning, floods, etc.), mechanical (agricultural equipment, construction sites in the vicinity, etc.), chemical and electro-chemical corrosion (ARIA 12507, 27681, 2257, 35286), etc.

The regular monitoring of pipes while taking into account related units and equipment (compression station, tracing, cathodic protection, connections, manifold, valves, etc.), timely surveillance of seasonal activity (agriculture) or construction (road works, etc.) carried out in the vicinity, as well as regular inspections and tests come next: ARIA 29864, etc.

The accidents whose references are not underlined may be consulted at:  
[www.aria.developpement-durable.gouv.fr](http://www.aria.developpement-durable.gouv.fr)

    **ARIA 7128 - 19/11/1984 - MEXICO - SAN JUAN IXHUATEPEC**

**35.22 – Supply of combustible gases through pipes**

   During the filling phase of an LPG storage area (mixture of 80% butane - 20% propane) comprising 2 spherical tanks of 2,400 m<sup>3</sup>, 4 of 1,600 m<sup>3</sup> and 48 cylindrical tanks (5,000 m<sup>3</sup>), a pipeline at 8 to 4 bar ruptured. A 150 X 200 X 2 m was formed and ignited after 5 to 10 min at a flare that 120 - 150 m away from the leak site. The VCE caused the BLEVE of the two small spherical tanks after 5 minutes. A fire ball with a diameter of 600 m was formed at the ground level. The zone was destroyed and the populated decimated within a radius of 300 m. Successive explosions occurred until 11.00 am. The fragments of the spherical tanks were projected as far as 600 m as well as 12 fiery rocket shaped fragments (20 tonnes) of horizontally placed cylindrical tanks were projected at a distance of 1m to 1,200 m. More than 500 people died, 7,000 injured and 39,000 evacuated and 4,000 rescue workers were involved in the operations.

    **ARIA 22249 - 23/12/1987 - IRELAND - COBH**

**20.14 – Manufacture of other basic organic chemicals**

   In the ammonia manufacturing unit of a petrochemical plant, a 24" pipeline carrying synthesis gases (43% hydrogen, 14% nitrogen, 12% carbon dioxide and 29% water) ruptured causing the resulting hydrogen cloud (60 kg) to explode. Even though the explosion was heard as far as 2.5 km from the site, the damage caused outside was limited (shattered glass panes, damaged roof). Under the effect of low pressure, an 8 m pipe that was further down rotated by 380° while another 12 m pipe that was further up rotated by 90° damaging a nearby rack and destroying the vent header of a desulphurisation unit of the refinery from where 600 kg of methane leaked and ignited. Hydrogen from the pipe further up ignited as well forming a 70 m long fiery stream. The alert was sounded and the units secured one after the other. The blaze was put out 5 min later by cutting off gas supply to the plant. Due to this emergency shutdown, ammonia was released into the atmosphere without any reported impact on the population or environment. The material damage on account of the accident was estimated at 0.65 M euros. The pipeline ruptured due to the fatigue induced by thermal cycles. The rupture zone of the pipe connecting a converter to the CO<sub>2</sub> absorber of the ammonia unit was near the water injection point that cooled the synthesis gas from 230°C to 179°C under 28 bar. The examination of the zone revealed several fatigue cracks on the internal wall of the pipe over a distance of 3 m from the water injection point. Moreover, the water injection nozzle that was probably distorted before the accident modified the direction of the stream but there was no proof to ascertain it as one of the causes of the accident. Lastly, several leaks on account of fatigue were identified on the pipeline over the past two years but were incorrectly diagnosed. The operator believed corrosion due to stress to be the cause. As part of the accident feedback, the facility was modified. The water injection system was replaced with a reboiler system. A general inspection was carried out in the facility with a view to identify similar phenomena. A preventive maintenance plan was implemented.

    **ARIA 2257 - 08/04/1990 - SEINE MARITIME (76) - PETIT-COURONNE**

**23.2Z – Manufacture of refined petroleum products**

   Since at least 1985 there had been leak on a corroded underground pipe conveying unleaded premium gasoline between a storage tank and a petroleum pier. This leak polluted underground water and eventually a DWS (drinking water supply) reservoir had to be abandoned. Gaseous fumes, however, propagated via the cities technical ducts and eventually caused a home to explode 2 km away, most certainly ignited when the hot-water heater tripped on. Twenty days later, a hole measuring just a few square millimetres was found on the corroded piping. More than 15,000 m<sup>3</sup> of hydrocarbons had been lost and more than 13,000 m<sup>3</sup> had been pumped into the water table. The operator compensated the homeowners by purchasing their home, and paid compensation to the water distributor and local community. The total cost of the work involved exceeded 50 MF.

    **ARIA 3325 - 30/05/1991 - 13 - BERRE-L'ETANG**

**20.14 - Manufacture of other basic organic chemicals**

   A leak occurred on a 10-inch ethylene tube at 45 bar following an electrochemical corrosion of an above ground section and an underground section protected by a protective sheath. It took 20 min to shut the isolation valves (2 km). Despite the safety perimeter set up, a vehicle from an outside company in the vicinity stalled, ignited the smoke upon re-starting and lit a 15 m flare turned towards a 6 m high rack supporting 10 pipes. A second 6-inch ethylene pipeline ruptured and caught fire. A section of the latter fell near the first pipeline that exploded. The fire spread to a warehouse storing 22 m<sup>3</sup> of solvents in barrels and 1,000 tonnes of synthetic rubber 20 m away. The quantity of ethylene involved in the accident was assessed to be 32 tonnes. Four people sustained injuries including one person who was severely burnt. Production losses stood at 220 MF. In January 2004, due to lack of maintenance of the pipelines in question, the former site manager was given a 10-month suspended sentence and fined 8,000 Euros, a first-line supervisor of the company operating the ethylene pipeline was given a 6-month suspended sentence and fined 1,000 Euros, an engineer of the same company received an 8-month suspended sentence and was fined 3,000 euros. Five other people facing prosecution were discharged.

**ARIA 16863 - 07/12/1999 - 38 - GRENOBLE**

**36.00 – Collection, treatment and supply of water**

A district (200 x 400 m) of the city of Grenoble was flooded with 20,000 m<sup>3</sup> water following the rupture of a big pipeline with a diameter of 500 mm. It was hard to determine the location of the leak that was stopped only after 2 hours and 30 minutes due to the high flow rate. The flood caused short-circuits and several start of fires in shops that were quickly extinguished by fire-fighters. Gas and electricity companies were also on site. About a hundred customers from a restaurant were evacuated. The district was completely dried only the following day at around 9.00 pm.

    **ARIA 14689 - 22/01/1997 - GERMANY - WASUNGEN**

**35.22 - Supply of combustible gases through pipes**

   An explosion occurred and was followed by fire in a liquefied combustible gas storage and supply facility. The pump room, electric control room and a part of the regeneration workshop were destroyed. One employee sustained injuries and another one was in a state of shock. Material damage was assessed at 350,000 DM. After investigations the gas pipelines and other underground protective electrical sheaths were not found to be airtight due to the presence of rust. Consequently, the gas infiltrated into the ground. Given the weather conditions (soil frozen at that period), the gas could not diffuse into the air and thus travelled through the leaking pipes below the building to reach drainage areas not connected to the sewage network. An explosive mixture was gradually formed and spread to the surrounding areas comprising rest rooms and wash rooms where even lighting a cigarette could cause the cloud to explode. Equipment and related devices (hoses in liquid or gas phase, loading arm, etc.) were replaced in the product transfer area with tanker trucks. A gas detection device controlled by an automatic emergency shutdown mechanism was also installed.

     **ARIA 19380 - 06/12/2000 – UNITED STATES OF AMERICA - JAL**

*49.50 – Pipeline transport*

    A pipeline with a diameter of 40 cm located 90 cm below the ground and transporting natural gas exploded in a gas conditioning plant. Two tanks situated below the pipeline, one containing methanol and the other glycol ignited in turn. The reason behind the explosion is not known. The explosion created an over 7 m X 6 m X 3 m crater. The fire was confined to the crater, put out by with mud and brought under control in 2 hours. The section on the pipeline was isolated both upstream and downstream. The plant was no longer supplied and had to be temporarily shut down. The section in question was repaired and all sections likely to be impacted by the accident were inspected. A specialised body was called in to investigate the accident.

     **ARIA 23839 - 12/17/2002 - HAUT RHIN (68) - CHALAMPE**

*24.1G - Manufacture of other basic organic chemicals*

    During efforts the previous day to locate the source of a pressure drop on the cyclohexane supply line of an olone production facility, a leak of this substance was discovered at a chemical site. The substance, used in large quantities, is of relatively low toxicity, although it a pollutant and flammable. Stored in a 10,000 m<sup>3</sup> reservoir, the cyclohexane is supplied to the olone and adipontrile (ADN) facilities by a partly common pipeline. Maintained at the proper temperature by a steam system, the cyclohexane is transferred at 20°C and at 2 to 3 bar through lagged overhead or buried piping. With an output ratio of 266:1, 2 pipes, 100 and 40 mm, provide a continuous supply to the olone shop and a discontinuous supply to the ADN shop. The leak occurred from the rupture of the ADN shop's 40 mm pipe due, according to the operator, to the dilation of liquid cyclohexane in the overhead part of the pipe between two blockages of crystallized cyclohexane. A malfunction of the pipe heating device (T < 6.5°C) led to the formation of blockages, with the cyclohexane then reliquifying primarily in the section the most exposed to the outside heating. As the piping was not yet equipped with a device for rapid leak detection, it took 30 hours to determine the cause of the pressure anomaly. The operator initially estimated the leak at just a few m<sup>3</sup> of cyclohexane, then between 850 and 1,200 t in the following weeks, the vast majority had migrated into the ground. A few days later, core samples taken at a depth of 13 m (the depth of the water table) showed the presence of a layer of cyclohexane localized near the site of the leak; lowering of the water table by one of the wells of the site's hydraulic security barrier would have limited the spread of the pollution. Analyses of the water table off site showed no trace of cyclohexane above the drinkability threshold. On July 2, 2003, 420 t of cyclohexane were pumped from the water table and 16 t extracted from the ground through venting techniques... In July 2004, 590 t of cyclohexane had been recovered, although cleanup operations had slowed considerably since the first of the year, with the quantities of cyclohexane recovered stabilising around ten tonnes per month. Consequently, a Prefectoral order was issued July 28, 2004 to request that risk analysis be conducted within the scope of a remedial plan.

     **ARIA 27681 - 30/07/2004 - BELGIUM - GHISLENGHIEN**

*49.50 - Pipeline transport*

    The gas pipe connecting Zeebrugge to the Franco-Belgian border exploded violently in an industrial zone. Around 8.30 am, a leak was detected by the hissing sound made by the escaping, still odourless at that stage. The emergency services arrived for the rescue operations in the area located near a construction site of an abrasive tool manufacturing unit comprising around thirty workers. The gas pipe was located 1.10 m below the ground (diam: 1 m; P= 80 bar). At 9.00 am, a violent explosion was felt several kilometres away along with the formation of a massive fire ball (200 m high and 500 m in diameter). The fire spread to a neighbouring petrol station and construction site and destroyed them. The gas pipe was isolated. As of 8 September, the human casualty toll was very high: 24 people died (5 fire-fighters, 1 policeman and employees of the neighbouring companies), 50 people sustained serious injuries (mostly burns) and were hospitalised in Belgium and in the north of France and 79 people sustained light injuries. The most serious state of emergency was declared and a federal crisis unit was set up. Residents were asked to stay indoors and the E429, A8 motorways as well as the No. 7 national highway were closed unit late afternoon. The country deployed significant human and material resources (5 helicopters, army) with backup from France (65 rescue workers, 13 ambulances, helicopters, and an advanced medical unit), Germany, Luxembourg and the Netherlands. Significant and wide spread material damage was reported. According to witnesses these include an approximately 10 m diameter and 5 m deep crater, several hundred m of burnt area, cars burnt to a cinder as far as 500 m, debris scattered up to 6 km. A 6 tonne (?) section of the pipeline was recovered at 150 m. According to the press, suspicious marks (depth: 10 mm) were observed on the recovered section that supports the operators theory of the gas pipe already damaged by a public works vehicle. The operator also added that a change in the operating mode of the pipeline along with the damage caused led to the leak. The pipeline resumed operation on 10.09.04. The adjacent pipeline slightly damaged by the accident resumed functioning on 09.08.04. The final human casualty figures stood at 24 deaths and 132 injured. On the basis of the legal and expert report that estimated that the operation carried out a few months back had damaged the pipeline whose location moreover had not been clearly indicated to the parties involved in the site, the Tournai Public Prosecution confirmed the aforementioned theory and indicted eight natural persons and seven legal persons including the network managing company.

     **ARIA 32818 - 01/10/2004 – NETHERLANDS - STEIN**

*20.14 - Manufacture of other basic organic chemicals*

    A leak detected late on a pipeline (10", 2 bar) serving a port petrochemical site along the Juliana canal was the caused 3 000 m<sup>3</sup> (2500 tonnes) of methyl tertiary butyl ether (MTBE) to be released thus polluting soil and underground water. The MEUSE river flowing nearby was also polluted. The pumping of the river waters meant for human consumption (300 000 persons) had to be stopped.

The leak was detected in October 2004 after a detailed inspection of the pipeline further to problems in the material balance. The leak in all probability lasted long and went undetected during the yearly inspections. The accident occurred due to faulty construction of the pipeline in 1976. The pipeline was built simultaneously from both ends to save time and required the assembly of an S-shaped threaded fastener due to a 70 cm difference in height between the two sections. The welding of the poorly cut component (1.5 cm gap filled in by welding) was apparently not in line with the best practices in the industry and was not inspected. The crack probably grew in size with time and under the effect of ground movements.

Several measures to clean up the site were deployed: excavation of polluted soil, pumping of MTBE, blowing air through the water table and subsequent treatment of the return air, etc. Moreover, a 15 m deep dike separating the Juliana canal was reinforced by a 15 m steel wall (below the ground water level).

In April 2005, 6 months later, the pumping station located 30 km downstream the Meuse river detected a significant hydrocarbon pollution which was later on identified as MTBE. After investigation, it was found that the point of origin of the pollution was at the petrochemical port: an 800 m x 200 m pollution zone of 300 mg/L of MTBE was detected between the accident site and the Meuse river, polluting the river at a rate of 50 to 100 kg / day. A treatment device covering a wider area was put in place in the beginning of 2006.

      **ARIA 29864 - 05/21/2005 - ISERE (38) – CHAMPAGNIER**

*24.1E – Manufacture of other basic inorganic chemicals*

      An explosion ripped through a pipeline transporting gaseous chlorine between a chemical platform (producer) and an elastomer manufacturing plant (user). The piping, built in 1961 to transport hydrochloric acid (HCl), was being used to convey deoxygenated and dried Cl<sub>2</sub>. Measuring 200 mm in diameter and       3,600 m in length, the painted, lagged steel pipe was equipped with an external skin effect heating system and operated at 4 bar (relative) and 30 °C. Production operations had been stopped the day earlier for a 10-day maintenance shutdown period, and the pressure in the 'chloroduc' had been lowered to 0.25 bar. The explosion occurred 150 m from the delivery point, in an area outside the user's site. The pipe ruptured in 4 locations along a 70 m section and showed traces of internal shock waves. The accident did not claim any victims despite a large amount of pipe debris projected in a 150 m radius. An estimated 475 kg of Cl<sub>2</sub> was released following the explosion. The damage observed (helical rupture, pressure wave...) indicates the explosive character of the accident. The 4 other pipes on the aboveground rack (dia. 100 mm) suffered extensive damage: the 2 nitrogen lines (13 bar, 2 to 3,000 m<sup>3</sup>/h) were deformed although were not leaking, and their pressure as reduced to 10 bar; the oxygen line (10 bar), was also damaged and was drained. The last line was no longer in use and was kept under N<sub>2</sub> at atmospheric pressure. Analysis of the accident showed that an H<sub>2</sub>/Cl<sub>2</sub> explosion caused the damage. The formation of H<sub>2</sub> (20%) can be explained by the combination of several elements: The accidental introduction of humidity into the piping during a previous maintenance operation may have led to hydration of the ferric chloride present in the pipe's environment. According to the operator, the change in the deposit's crystalline phase due to excessive heating of the pipe (80 to 90 °C) promoted corrosion in the steel pipe (by the hypochlorous acid) and the formation of H<sub>2</sub>. This heating caused a temperature sensor to lose its electrical power supply after a cable on the user's site was broken when a slab protecting the structure was poorly handled, just 3 days earlier. In fact, the proportion of hydrogen (20%) released in the gaseous chloride contained in the pipe, which was capped at each end and kept at low pressure (0.25 bar), formed an explosive mixture requiring very little initiation energy to ignite (in the order of a dozen microjoules or so). The operator cleaned the inside of the structure (2.5 to 3 t of mineral and organic residues were extracted), and had planned to install temperature sensors every 500 m with upper and low safety devices, refurbish and secure the electric (heating) tracing, and perform regular endoscopic inspections...

      **ARIA 34176 - 20/10/2007 - UNITED STATES OF AMERICA - PORT ARTHUR**

*20 – Chemical industry*

      A pipeline carrying ethylene ruptured, exploded and caught fire at around 2.00 am in a chemical plant.       The fire spread to three other pipelines including one carrying butylene. Black smoke was emitted in the air, road traffic stopped out of precaution and residents facing the direction of the wind were advised to stay indoors. The fire was extinguished around 5.00 pm and road traffic was resumed. No casualties       were reported.

      **ARIA 35286 – 10/09/2008 – PONT DE CLAIX**

*49.50 – Pipeline transport*

      Around 11.30 am, the railway department reported a hydrogen chloride gas leak from a pipeline (MOP 8 bars, NPS 350) connecting two chemical plants due to the emission of fumarole. The surveillance and       contingency plan relating to the structure was triggered. The pipeline was depressurised and       subsequently drained by the employees.

The leak was caused due to localised external corrosion below the bridge over a stream. During repair operations, paint was directly applied to an iron oxide build-up without polishing the surface. Successive floods and the humidity below the bridge contributed to the corrosion. Water seeped in between the paint and pipe causing deposit corrosion. A specialised company temporarily fitted a watertight collar and a supporting prop onto the structure. The accredited inspection department of the company using the pipeline carried out an inspection on the 9 and 10 of October to ensure the absence of any area conducive to deposit corrosion (humidity, presence of water, retouching). The inspection led to the detection of a high-risk area, more specifically a pipeline passage on the same stream at about 50 m upstream to the previous zone showing corrosion. No additional faults were detected after further checks. The replacement of the pipeline section (20m) was planned during the next shutdown. Following the incident, the operator drafted a press release that was posted online on the company website.