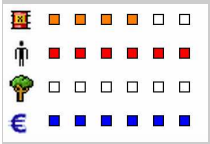
Rail accidents in urban areas

Derailment and explosion of LPG railcars

ARIA 36464 - 29/06/2009 - Italy - Viareggio

49.20 - Rail freight transport



Shortly after crossing a train station at a speed of 90 km/hr around 11:45 pm, the conductor of a convoy of 14 railcars containing 110 m³ (45 tonnes) of liquefied petroleum gas (LPG) felt a jolt and noticed the derailment of 5 tanker cars, which were laying on their side. He activated the emergency brake, stopped the engine, folded the pantograph and ran towards the station 200 m away for protection.
After hitting either an obstacle just beside the track or a rail switch, as evidence has confirmed, the first railcar steel was torn over a 40-cm length and a width extending between 2 and 5 cm, thus causing an LPG leak, along with the formation of a dense cloud that would subsequently explode (a UVCE type explosion) upon reaching nearby residences. An intense fire engulfed the premises ; two other explosions were heard a bit later, and another violent fire was blazing at the derailment site itself.
A state of emergency was declared for the entire region, triggering the deployment of over 300 fire-fighters, in addition to heavy assets from both the national and regional levels. The fires were extinguished by sunrise the next morning, while tanker cooling and site clearing activities continued throughout the day. Specialised units then relayed one another in order to empty the cars before being turned upright with a crane and fully discharged. This emergency response was completed 48 hours later.
The toll of this disaster came to 32 fatalities, with a few individuals succumbing several days afterwards, plus 50 injured, among whom 30 seriously hurt. Within a radius of 200 to 300 m, a single-family dwelling and 2 residential buildings were destroyed, while 4 others were heavily damaged with the collapse of a section of their living quarters; a total of 100 individuals had to be relocated. Windows were shattered over an even wider zone. Another 1,100 individuals were evacuated for safety reasons. Several vehicles burned and sections of railroad track were totally deformed by the heat. The extent of damage was estimated at €32 million.
The derailment had been caused by a fatigue fracture of the front axle of the convoy's first railcar. In conjunction with the judicial investigation, the railway undertaking ("contract operator") conducted separate investigations to determine the exact causes and circumstances surrounding the accident. The lead car and subsequent vehicles belonged to Polish and German railway undetakings. Placed into service in 2003 and 2006 respectively, these cars had undergone the required regulatory inspections in March 2009 and were scheduled for checking in December 2009. According to sources cited in the press, inadequate maintenance of these cars, whose axles were reported to be rusted, was also identified as a contributing cause.
This disaster was the most serious Italy had experienced in the rail transport industry for dangerous goods and moreover one of the country's most severe accidents ever catalogued involving the production and distribution of LPG. The initial feedback exposed a number of failings relative to :
- identification and evaluation of accidental events, safety analyses and residual risks (see the SEVESO Directive dedicated to fixed installations), along with the planning and updating of techniques and/or management solutions designed to mitigate risks. The high speed of railcars in the vicinity of a station (i.e. very dense rail traffic within an urban setting) would seem to be a major shortcoming regarding safety ;
- recognition of equipment scheduled for regular inspection, and definition of maintenance procedures. Adequate vehicle maintenance efforts, including the regular testing of railcar axles and other rolling stock, no doubt constitute another factor to be listed as one of the principal accident causes (i.e. fatigue failure) ;
- determination of responsibilities, resources and activity scheduling. The responsibilities of each actor involved in railcar management and mandatory inspections had not been clearly defined.

A working group devoted to freight railcar maintenance, assembled by the European Rail Agency (ERA), concluded its sessions by stressing the need to harmonise the various maintenance systems and protocols existing throughout Europe.

Rail accidents in urban areas

In France, three-fourths of the total tonnage of hazardous freight being hauled is shipped by road, 15% by rail and 3% by waterway, while the pipeline only accounts for a very small share of this transport activity.In 2009, 13.8 million tonnes (Mt) of hazardous freight were transported by rail (vs. 79.4 Mt by road), amounting to a 17% share of total rail freight volume. This type of transport is handled 75% of the time by full trains, with 95% of railcars being tanker cars, responsible for conveying: 6 Mt of flammable liquid materials, 5.2 Mt of various chemical products, and 2.6 Mt of compressed gas, whether liquefied or dissolved under pressure.

As regards prevention, the law adopted on 30 July 2003 introduced the requirement for transport infrastructure managers (of marshalling yards, road parking lots, maritime and river ports), whose facilities accommodate a large quantity of hazardous freight, to complete a safety report. A decree dated 3 May, 2007 specified the application conditions effective for this law, in addition to the legally mandated time frame for submitting such reports by May 2010. This decree also defined the thresholds at which point a safety report is to become mandatory.

This legislative framework was completed by Law No. 2010-788 enacted on 12 July 2010 (so-called "*Grenelle 2*", Art. 218), which confers upon the Prefect additional policing powers so as to penalise the failure to submit a safety report and, as needs arise depending on report contents, to impose structural and operating modifications.

All rail transport must also comply with the Regulation relative to international railway transport of hazardous freight (or the "RID" Regulation). Each railcar, dedicated to a given type of freight, must satisfy a set of resistance criteria defined for every category of hazardous freight, including considerations like corrosion resistance and removal of all porosity.

The rail transport of hazardous freight is responsible for 5 times fewer accidents per tonne transported than road transport, yet has always had the potential to cause very serious accidents, especially when track runs through urban areas, i.e. central city train stations, railways alongside residential dwellings.

The composition of materials transported and accident typology (ARIA 349 / explosion of pyrotechnical substances, 5382, 5895, 6919, 6938, 7436 / BLEVE, 26980 / collision of 2 trains carrying incompatible substances), as well as residential density and local population distribution, and the unique topography of certain sites (ARIA 4225 / sloped, street paralleling the track) provide a large number of factors capable of exacerbating the original accident, in terms of not only the number of victims, but also the subsequent damage and environmental impacts (ARIA 5642, 349, 5895, 26980 / number of victims, extent of affected zone).

The extensive and uncontrolled spreading of flammable liquids can also introduce major risks. The near-immediate and systematic ignition of such liquids generates a tremendous heat flow rate locally (ARIA 4225 / ignition of a building and meadow 100 m from rail tracks, 5073 / 80-m flames at 1,000°C) or is capable of leading to domino effects (ARIA 5382 / ammonia tank consumed in the flames). Sewers and other outfalls have in some cases worsened the situation by "streamlining" the flow of materials released over long distances, or by unexpectedly "shifting" the event and its consequences (ARIA 4225 / stormwater collector pipes and lift station located in the middle of a residential subdivision, 32592 / explosion, pollution of a river), while causing new risks such as ATEX (explosive atmosphere) zones, explosion and the projection of equipment, accessories, splinters, materials, etc. (ARIA 4225 sewer plates, 5073 / craters).

As regards feedback transposable to classified facilities in particular, this kind of spreading of flammable materials needs to be addressed in the safety reports and emergency plans specific to such installations. When accidents actually take place, a substantial deployment of responders and equipment becomes necessary to rescue individuals as quickly as possible and limit the spread of hazardous material flows through sewer systems and into the natural environment.

Major leaks of toxic liquefied gases, liquid substances or solids can also occur after the rupture or puncture of transport tanks (ARIA 5515 / epichlorhydrin, 7436 / CO_2, 16232 and 21199 / NH_3) or be feared to occur due to sensitivity of the given location (ARIA 16924 / herbicides); also taken into consideration herein is the emission of heavy toxic fumes (ARIA 5642 / leak and hydrolysis of phosphorus trichloride, 33274 / ignition of phosphorus carried by railcars).

Beyond the specifics of a given accident, including heat, explosion risk and the eventual presence of toxic gases, rescue teams may have to face a wide range of difficulties during emergency response, namely :

- organisational: roles and responsibilities of the various actors (ARIA 2438, 3468, 4225), large numbers of local residents to evacuate (ARIA 349, 5515), property to protect (ARIA 6938 / retail shops), relocation of damaged or deteriorated railcars to a safe depot prior to the eventual transfer of contents (ARIA 3468, 19326 / large-scale evacuation measures) ;
- technical: high-voltage electrical lines (ARIA 3468 / catenary lines), widespread electrical outages necessitating the use of autonomous means (ARIA 2438 / motor-driven pumps, 4225), leaks of hazardous materials difficult to clog (ARIA 3468 / a leak impossible to clog without custom-built equipment) or to transfer (ARIA 3468 / immersion rod, 21199 / hose and valve), reliance on special lifting and transport equipment (ARIA 3468 / crane and flatbed car, 35530 / cranes, 37598 / high-capacity flaring device), structural cutting and other hazardous operations (ARIA 39500 / risk of iron-chloride reaction) ;
- difficulties leading to pile-ups and domino effects (ARIA 5382 / BLEVE-type explosion involving an NH_3 car in a fire, 6919 / fire and several BLEVE-type explosions of LPG cars, projectiles reaching a filling station, 6938 / BLEVE explosion of LPG cars, fire inside a plant and neighbouring facilities, 26597 / explosion subsequent to contact between incompatible materials: sulphur, gasoline, fertiliser and cotton).

Following the initial emergency response, it becomes essential to quickly ensure the safety of all affected sites (ARIA 2438 / gas odours, cleaning of shafts and cellars, decontamination and ventilation of sewers, 4225, 5515), and then to assemble and implement both human and material resources for assessing and absorbing all eventual pollution (ARIA 2438 / choice and efficiency of treatment strategy, 4225 / use of a "proven" technique, 5073). Several catalogued accidents demonstrate that though the emergency response might only last a few hours, ensuring the site's safety could take several days, while pollution clean-up of contaminated zones and any eventual restoration work is capable of spanning many months.

A system for reducing risks at the source when dealing with this type of accident relies upon :

- the reliability of rolling stock, whose improvement depends on public authorities, responsible for establishing construction standards, as well as on builders assigned the implementation task, certified maintenance workshops dedicated to the equipment, car holders responsible for railcar condition, and shippers in handling their loading duties ;
- the introduction by some rail operators over the past few years of experts for transporting hazardous materials within each operating region, for the purpose of enhancing risk management on exposed sites. These experts are assigned to identify, notify and manage potentially hazardous situations, in collaboration with loading personnel and emergency response teams. Their mission also entails complementing responder training in the field and verifying procedural efficiency ;
- any train carrying hazardous substances now requires a permit to travel on pre-established routes, with a special transport plan adopted for radioactive materials. Continuous hazardous substance monitoring should, under normal conditions, indicate at any point in time the type and location of risks, as the rail infrastructure manager is required to maintain all corresponding information up to date and available ;
- signalling, by means of orange signs posted on railcars displaying hazard and material identification numbers, serves to identify the product being transported as well as the hazard it presents, while referencing the corresponding safety fact sheets ;
- As a complement to this set of information, police officials can also call upon the technical assistance of the shipper, who remains responsible for merchandise in the shipment, or instead upon the recipient. The TRANSAID protocol (signed in 1987 between the Interior Ministry and the French Union of Chemical Industries) also empowers emergency response teams to request input from competent technicians at chemical installations located closest to the accident scene, in order to obtain qualified assistance for several hundred different chemical products, in the form of information, advice and/or assistance and action at the scene ;
- lastly, the rules specific to the RID Regulation relate to the circulation and parking of tanker cars on rail network lines: railcar parking time limited according to the transport plan defined by the infrastructure manager (Art. 2.3.1.1 of the TMD decree governing the transport of hazardous substances), parking in dedicated zones.

As regards protection at the national level, the infrastructure manager prescribes measures to be adopted in the event of an accident or incident in accordance with rail operating principles. For each marshalling yard, the manager is required to implement a Hazardous Freight Plan. Designed as a decision-making aid for crises related to an accident/incident, this plan must :

- ensure the efficiency of emergency service alerts ;
- organise emergency response conditions ahead of time ;
- depending on the severity of the accidental situation, focus on the safety of individuals present onsite as well as on rail traffic safety (evacuation of all or part of the site) ;
- acknowledgment of information available on individuals present onsite and employees involved in permanent activities, by the dissemination of warning messages, as well as information on site foremen responsible for overseeing facility conditions.

These plans are developed through a coordinated effort with the emergency services. Their efficiency presumes incorporating the site's local specificities : type of hazardous substances, traffic volumes, quantities, site configuration and special vulnerabilities (urbanisation, water table). This requirement leads to differentiating Hazardous Freight Plans across sites, while all still target the same safety objectives. Hazardous freight plans encompass all activities taking place at the given site, whether performed permanently (e.g. workshops, depots) or on a one-time basis (through-trains, temporary building projects).

In all other train stations, the infrastructure manager is able to implement a Local Hazardous Freight Plan, which sets forth the guidelines for assigning each party's missions (employees, public safety services, etc.), in coordination with existing departmental safety plans at the periphery of each included site. These plans serve to assist public safety personnel as a crisis unfolds.

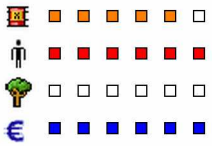
Periodic drills are organised each year in order to test the efficiency of these plans, while offering the opportunity for emergency services to better assess the local context and its evolution over time.

Additional references (detailed accident reports) :

- ARIA 2438: Derailment of a train transporting gasoline to Chavanay (42), on 3 December 1990.
- ARIA 4225: Derailment of a train transporting gasoline to La Voulte-sur-Rhône (07), on 13 January 1993.

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

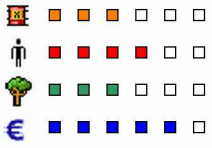
www.aria.developpement-durable.gouv.fr



ARIA 349 – 04/06/1988 - RUSSIA - ARZAMAS

49.20 - Freight rail transport

An explosion of 3 railcars loaded with 120 t of explosives caused 93 deaths, 700 injuries treated at emergency centres and 230 hospitalisations. Property damage was extensive: 150 houses destroyed and damaged, 600 families left homeless and 90,000 residents evacuated. Window panes were shattered over a 15-km² area.



ARIA 2438 – 03/12/1990 - 42 - CHAVANAY

49.20 - Freight rail transport

A 22-railcar convoy derailed at 11:50 pm in a small town of 2,000 residents; 9 tanks carrying 80 m³ of unleaded fuel spilled, ignited and exploded. This burning gasoline consumed dwellings and reached the sewer system. Electricity had to be shut off and vehicle traffic diverted. The fire was brought under control by 6:30 am on the 4th following the intervention of 180 fire-fighters equipped with separate resources (e.g. motor-driven pumps).

A village resident was injured, 34 others housed elsewhere. The accident zone extended over 1 km strip 400 m wide; 8 dwellings, 2 garages and 30 cars were destroyed, and another 5 houses were damaged. 250 to 300 m³ of gasoline polluted 2 ha of ground. Potable water extraction zones were threatened 100 m away and "gas" smells were reported on several nearby properties. The use of agricultural wells was prohibited, water pumping was restricted, and fruits and vegetables ruled unfit for consumption within a 12.5-ha zone. Administrative decisions were quickly made to demolish the affected dwellings.

The municipality and rail operator contracted a pollution cleanup firm; 10% to 20% of the hydrocarbons (HC) were combusted or had evaporated, while 80% to 90% of gaseous or liquid HC were trapped in the soil layers above the water table (i.e. "unsaturated zone"), both in the rail embankment and at the surface of the water table within a thin clayey formation at the base of a hillside. The shafts and caverns were cleaned. The polluted zones were treated with water table drawdown (16 m³/hr via 3 pumping stations), reduction of the polluted zone by characterising the subsoil and contamination (an expert body, 40 boreholes), then a 3-stage cleanup :

- pumping/skimming of the water table: 40 m³ of HC recovered during a 17-month period, with discharge into the Rhone River of all drawdown water containing less than 20 parts per million (ppm) of HC ;
- bioleaching testing, through probing in vain beyond 2 m of depth, this stage would be abandoned ;
- highly efficient vacuum extraction (venting), giving rise to a call for tender with quantifiable objectives: HC content of soils no greater than 10 ppm, absence of HC supernatant in the water table following 1 year of cleanup.

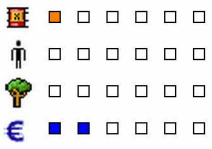
After 45 weeks of treatment, 210 m³ of HC were extracted from the parcels not returned to their owners, but instead expropriated by the municipality for public facilities, thus simplifying the adoption of soil/subsoil use restrictions included in land use planning documents, in order to guarantee a long-term use allocation compatible with the presence of residual pollution.

The public investigation pointed to excessive train speed (93 km/hr) with respect to the defect ("warping") of rail track, whose foundation was weakened subsequent to heavy rains. For the railway operator, the cost of this accident amounted to 28 MF (1991 currency) in emergency measures, studies/pollution cleanup of the site, plus another 22 MF in compensation (third-party losses / municipality).

After the initial emergency response, the municipality, railway company and administrative authorities had to make quick decisions to assess the actual/potential extension and consequences of the pollution, before implementing suitable measures aimed at preventing propagation, without the time to estimate their duration/costs in the absence of clearly-defined lines of responsibility.

This vacuum extraction, or venting, technique was again used a few months later following another accident on this same section of track 100 km further south (ARIA 4225). The bioleaching tests demonstrated that the pollution cleanup technique depends on both the pollutants and the target media, i.e. type of soils, permeability, water table depth, flow velocity.

As regards feedback applicable to classified facilities, the potential consequences of this kind of accident imply the emergency use of resources in order to contain flow, before implementing other resources to evaluate and absorb the pollution. The massive, uncontrolled spreading of flammable liquids could generate high risks, especially during network flows (e.g. ATEX Directive). Such situations need to be taken into consideration when drafting safety reports and emergency plans.



ARIA 3468 – 16/03/1992 - 73 - AIX-LES-BAINS

49.20 - Freight rail transport

A 28-railcar convoy, with 3 cars carrying hazardous substances, derailed at 2:25 am right at the train station in the middle of the city, just a few tens of metres from the closest residential buildings. The 11-kV drop in cables on the overturned railcars triggered the ignition of a 20-tonne tank of dimethylamine (DMA). 20-metre high flames were observed; moreover, 2 nearby cars contained 40 tonnes of ammonia (NH_3) and 20 t of methyl ethyl ketone (MEK). Some of the catenaries were ripped out, while others were deformed by the heat.

Notified at 2:30 am, a team of 50 fire-fighters arrived at the scene 7 min later with the appropriate foam. The fire was extinguished at 3:50 am, but a malodorous cloud led authorities to: introduce a 400-m safety perimeter, order the evacuation of buildings in the vicinity, and request all other neighbours to remain indoors. The cloud was diluted with a water curtain. A leak ultimately identified around 5 am on the DMA railcar was only precisely located on a flange of the damaged drain 5 hours later.

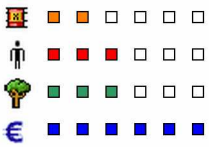
An Operational Control Station was set up at 10:30 am, at which point the Prefect activated the TRANSAID procedure. As of the beginning of the following afternoon, both the municipality and prefectural departments regularly informed the population either directly or through distributing flyers.

Emergency services were unable to install a new flange without the assistance of specialists, who were being actively sought. By 5:30 pm, the leak was 95% plugged. A customised "bell" was installed on 17 March at 6 pm for the purpose of better controlling the residual emissions. Sprinkling of the tank was halted, and the DMA caught by the bell was neutralised by dissolution in water.

After a full day of assessing the situation, all onsite transfers were stopped; the DMA car from then on was to be raised and moved t a safer place within the special convoy. These operations were prepared down to the finest detail, then the DMA car was raised on 18 March at 6:10 pm and removed at 8:24 pm onto a lower-level platform 20 km from the accident site; since the convoy was unstable, the journey lasted nearly 3 hours at 8 km/h. The car was then placed upright on 19 March and cooled with carbon dioxide (CO_2) in order to balance the pressure and void using an immersion rod. The slightly-damaged car carrying NH_3 would be towed to its final destination.

Thanks to an overall favourable context, as well as the tank design and quick response time by the emergency services, the accident exerted no major impact on the environment, although the municipal treatment plant was minimally polluted by runoff water through the stormwater drainage network. Trains were allowed to resume circulation on 20 March around 6:30 pm.
Six cars left the track (nos. 3 through 8). The 3rd of these, a two-axle grain carrier, empty and intended for the scrap yard, derailed 1 or 2 km from the station. Arriving out of alignment, this car slammed into containers and docks, causing derailment of subsequent cars.
This accident highlighted, at the very least, the need to draft as quickly as possible Specialised Emergency Plans for the Transport of Hazardous Substances, as indicated in the pertinent regulations (Circular 88/404, issued 22 November, 1988).
The Transport Ministry assembled a special public investigation commission in order to determine/analyse the causes of this accident and draw lessons in the area of prevention and organisation of rail transport system for hazardous substances. Some 30 recommendations were relayed to the rail operator in order to:

- define preventive measures on the equipment and track to avoid derailment risks and ensure their rapid detection;
- improve the safety of hazardous substance transport;
- build an assessment of the factors leading to derailments (through both a theoretical approach and feedback);
- help clarify responsibilities of the various actors in the handling of serious accidents;
- participate actively in the development of emergency plans, within the scope of the action plan initiated by the Interior Ministry.



ARIA 4225 – 13/01/1993 - 07 - LA VOULTE-SUR-RHONE

49.20 - Freight rail transport

A 20-car convoy left a tunnel around 11:30 pm in order to cross a train station when 7 tanks carrying 80 m^3 of gasoline derailed. An axle with an overheated bearing housing broke on one of the railcars. Traces on the rail ties and ballast attest to the fact that this car followed the convoy for a distance of 300 m and left the track in the direction of a rail switch 100 m or 150 m ahead of the derailment.
With a shell torn over 1/3 its length and a bottom check valve torn off, 4 of the tanks emptied their contents, a violent fire broke out, and the rail conductor moved the remaining cars out of danger. 15 to 20 minutes later, one of the cars overturned and opened, leading to an explosion and fireball; the heat flux alone burned a dwelling and field located 100 m from the tracks. Streams of burning hydrocarbons (HC) spilled 20 m below onto a street lined with buildings, which served to channel the ignited gasoline; a total of 15 houses and 15 vehicles were destroyed. Cast iron sewer plates were projected some 15 to 20 m high, then a fire and series of explosions destroyed the stormwater pumping station 250 m downstream, preventing pollution from flowing into the Rhone River.
The fire was extinguished during the morning by a crew of 250 fire-fighters. Within a 600 m perimeter, 1,000 individuals were evacuated at night; 6 injuries were reported. The conductor and 2 residents sustained skin burns, 3 others suffered fractures and contusions while escaping the flames.
Commissioned by the municipality and rail operating company, a consultant assessed the consequences of this accident and monitored the introduction of site safety features: cleaning/inerting of sewers by pumping and ventilation (3,000 m³/h), inventory of access points, inspection of gas contents and collector pipes to eliminate eventual pockets of HC. Then came the pollution cleanup effort: 20 m³ of the remaining HC inside the railcars; 300 m³ lost; 200 m³ burned/evaporated during explosions (either in sewers or after ventilation); and 100 m³ in the soil and water table (from 1 to 4 m deep). Yet municipal water collection further upstream was not compromised.
Within a few hours, 16 piezometers were drilled into place. In 4 days' time, 110 water samples and 250 "gas" measurements were performed in the soils, on a daily basis for a week, allowed evaluating the pollution. Heat from the fire facilitated degassing of the soil, yet the measurements still indicated a 1-m deep pollution in the embankment underneath the tracks (covering 1.1 ha), as well as subsoil in the urbanised part of the embankment reaching 80 m (1.5 ha). HC contents exceeding a max of 2,500 ppm were recorded in the instruments. A CNR drain along the embankment drained the floating HC, with a portion being recovered prior to the station. To draw down the water table, 5 wells (1.2 m in diameter) were dug beginning on 18 January, 1993.
The zones with persistently abnormal values were to be ventilated and cleaned. Used previously after an accident on this same track in December 1990 (ARIA 2438), the selected "venting" technique limits treatment time and costs. To both the north and south of the polluted parcels, 2 networks placed the soils in depression (differential pressure = 250 mbar) and a hydraulic dam completed the set-up on the eastern side. All drained HC were incinerated in 2 mobile furnaces. 98% of the HC was recovered within 4 months, during which time 100 people had to be housed in new accommodations.
According to the rail company, the rehabilitation and compensation costs (for third parties and the municipality) amounted to 70 MF (1993 currency), including 15 MF to rebuild the station and another 5 MF on treatment. Shortly thereafter, the company created an entity for the purpose of monitoring the isolated railcars (diffused traffic) and convoys in real time, in addition to providing advice and information in the event of a transport accident in order to make prudent use of public sector emergency response services.
Whether in transporting hazardous substances or at classified facilities, the potential consequences of a massive uncontrolled spreading of flammable liquids implies an emergency intervention to limit propagation and quickly implement the resources that allow evaluating and treating the pollution. Substantial risks, especially in the case of network spills (covered by the ATEX Directive), need to be incorporated into safety reports and emergency plans.
Beyond the initial response, attention quickly turned to the issue of limiting the scope of subsoil and sewer network pollution by hydrocarbons. The entities present (municipality, rail transport company and administrative authorities) had to cope, under emergency conditions, with the need to make decisions to evaluate, without delay, extension of the pollution and the seriousness of actual and potential consequences. They were also faced with implementing measures to prevent the spreading of hydrocarbons, even though responsibilities had not been clearly defined and no estimation of either the duration or costs of these measures was available.

ARIA 5073 – 08/03/1994 - SWITZERLAND - ZURICH

49.20 - Freight rail transport

Following an axle break, one of a train's 20 railcars, each of which contained 75 m³ of gasoline, derailed, caught fire and exploded at the station. The fire reached 4 other railcars, destroyed 3 buildings alongside the tracks and damaged a 4th building set back slightly (80-m high flames, 1,000℃). The gasoline flowed into the sewers and caused explosions (10-m diameter crater); a stormwater collector pipe was also damaged (total damage in excess of 30 MF). The district was evacuated for a day (200-m radius, 120 individuals); 1 serious injury and 2 slight injuries were reported, including one responder (projections sewer plates). Local river fauna was impacted. Two explosions occurred subsequently, one the very next day (caused by a spark from a crosscut saw). Total damages were estimated at 200 MF.

ARIA 5382 – 08/04/1979 - UNITED STATES - CRESTVIEW

49.20 - Freight rail transport

Following a derailment, a fire and series of explosions (of the BLEVE vapour explosion type) occurred on railcars transporting flammable products. A railcar carrying ammonia, caught in the fire consuming cars carrying acetone, methane and chlorine, exploded 20 minutes after the fire broke out. A total of fourteen injuries or intoxications were reported, along with 4,500 evacuations within a 2,500-m radius. Fragments of railcar shells were projected up to 200 m from the site of the accident. The investigation outcome pointed to a criminal attack.

ARIA 5515 – 29/06/1994 - SWITZERLAND - LAUSANNE

49.20 - Freight rail transport

A train derailed at 2:56 am at the Lausanne rail station; 7 of the 50 cars on this 690-m (1,753-tonne) convoy were on their side on the track. Two cars transporting a total of 80,000 litres of epichlorohydrin leaked, allowing 400 litres of a toxic, volatile and flammable chemical product to escape.

The alarm was sounded at 3:14 am, with over 500 fire-fighters arriving at the scene to: plug the car openings, recover the product that had spread, and ventilate the sewers. The entire district, accounting for 1,500 residents, was evacuated as a safety measure during the emergency response. No injuries were reported. Over the ensuing 4 days, the tanks of both epichlorohydrin and thionyl chloride were emptied, the overturned cars were placed upright, discharged or returned to their recipients. The local population would have to be evacuated a second time when performing hazardous operations (e.g. standing the cars upright).

The accident was caused by a switching error. The train entered the station on track no. 3. When it crossed onto switch 76a, on the eastern side of the station, the 25th railcar (which was rolling empty on its 2 axles rose, then fell adjacent to the tracks and stayed on its path by rolling along the railroad ties, while being supported by the platform edge. The train was making a service stop at the station in order to rotate conductors; however, upon restarting the convoy, the wheels on the derailed car remained trapped between the rail and the platform edge. At the end of the platform, in the track switching zone, the 2 cars preceding the empty car, along with the 11 subsequent cars, derailed. Of these 14 cars that left the rails either totally or partially, 5 of them, including 3 tanker cars containing hazardous freight, were lying sideways on the track. The one was transporting thionyl chloride and the other 2 epichlorohydrin. The first epichlorohydrin tank was slightly punctured, which caused the contents to flow out. The cars containing hazardous substances damaged in the accident carried respective capacities of 47,000 litres of epichlorohydrin and 24,000 litres of thionyl chloride.

ARIA 5895 – 19/07/1974 - UNITED STATES - DECATUR

49.20 - Freight rail transport

In a marshalling yard, operator error caused a perforation in back of a tanker car. A 63-ton cloud of isobutane dispersed over a zone spanning 800 m by 1,200 m. The ignition occurred between 8 and 10 min after the rupture of the car. The explosion killed 7 employees, and 349 injuries were reported, including 33 among the personnel. Windows were shattered up to 4.8 km away; a total of 700 dwellings were damaged within a 5-km radius, in addition to 11 public buildings. Major structural damage was recorded out to a distance of 1.6 km. Another 283 other tanker cars were totally destroyed and 312 damaged. The TNT equivalent of the blast was evaluated at between 20 and 40 tonnes.

ARIA 6919 – 21/06/1970 - UNITED STATES - CRESCENT CITY

49.20 - Freight rail transport

In a rail convoy, a sand hopper derailed, causing the subsequent derailment of 9 propane cars. After being perforated, one of the propane cars ignited spontaneously. The heat released then triggered the safety valve on a second car, creating a torch flame that in turn exploded a third car (BLEVE, vapour explosion). A fragment of car was blasted 180 m, and another piece slammed against the roof of a filling station, causing its collapse. The second car exploded 2 hours later. One of its fragments was projected 500 m. A fourth car exploded, destroying 3 buildings located along its trajectory. 35 minutes after that, another tank broke, followed a short time later by 2 new cars. The fragments of one of these last two wound up causing explosion of the last 2 tankers. In all, 66 people were hurt.

ARIA 6938 - 5 July, 1973 - UNITED STATES - KINGMAN

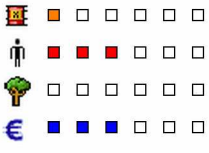
52.21 - Auxiliary land transport services

A small leak was noticed during transfer operations on a railcar containing 75 m³ of LPG. 1 of the 2 technicians on duty attempted to close the valves using a tool made of aluminium, which may have been the cause of the ensuing gas ignition. He was burned alive, while the other, who sustained serious burns, sounded the alarm. Fire-fighters did not arrive until 25 min later. Tremendous flames emanated from the railcar. Fire-fighters tried to cool the car, but their efforts proved insufficient, resulting in a BLEVE-type vapour explosion. Half the car was projected 365 m. A fireball 45 m to 60 m in diameter could be seen. 5 buildings caught on fire. 12 fire-fighters were burned to death, and 95 injuries were reported. Burning debris ignited a plant, restaurant and store (domino effect). The fires were brought under control after an 8-hour fight.

ARIA 7436 – 02/09/1976 - GERMANY - HALTERN AM SEE

49.20 - Freight rail transport

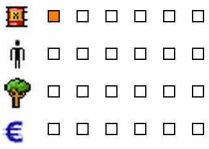
Rolling at approx. 16 km/hr in a marshalling yard, a tanker car (90% full) carrying 231 t of liquid CO_2 (-15°C, 7 bar) exploded, though its safety valve remained open. According to various witness accounts, the BLEVE-type explosion had occurred slightly beforehand, i.e. just after this car had made contact with another group of railcars. One person was killed. The tanker chassis was folded into a "V" shape; 22 fragments, accounting for approx. 80% of the tank were projected over a wide range of directions, with angle ranges of 5°-20° and 65°-95° relative to the railcar direction. Some of the projectiles would be found over 360 m away; 3 empty cars positioned on 3 different tracks further down the line were overturned. An analysis of the fragments pointed to a brittle fracture as the cause of the tank's failure.



ARIA 16232 – 24/07/1999 - UNITED STATES - IDAHO

49.20 - Freight rail transport

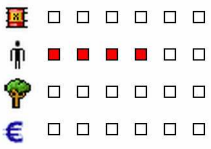
During derailment of a 69-car convoy, 135 m³ of ammonia (NH_3) from one of the cars were released into the atmosphere. 6 ammonia cars plus another 6 cars (transporting wood, stones, etc.) fell into the adjacent riverbed. More than 200 local residents had to be evacuated, 2 highways were closed. Several cars were damaged, and a few people were intoxicated by the release. The rails punctured one of the cars, whose entire contents evaporated. A state of emergency was declared during the night and evacuations proceeded over 32 km². A few hospitalisations were recorded. Highway traffic was reopened around 9 am the next morning. A car carrying stones had missed a switch, deteriorating 60 m of track and causing the derailment. The alarm was sounded by an eyewitness who heard the accident and smelled the NH_3.



ARIA 16924 – 21/10/1999 - AUSTRALIA - SYDNEY

49.20 - Freight rail transport

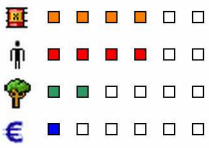
Six railcars on a freight train carrying herbicides, fertiliser, sodium cyanide and various chemical products derailed. Out of precaution, response teams set up a 250-m radius safety perimeter and evacuated population near the derailment site (5 houses) for 2 hours. Motorists were detoured during the cleanup phase. Similar precautions for air traffic, which was suspended at a radius of 3.2 km and height of 600 m. Formation of a highly toxic cloud was feared in the event of a sodium cyanide leak. Yet none of the product barrels leaked. Over 40 chemical products were present in the train, and the leak volume was estimated at 40 t of herbicides. The situation was brought under control within 36 hours.



ARIA 19326 – 28/11/2000 - 26 - PORTES-LES-VALENCE

49.20 - Freight rail transport

A tanker car on a 21-car rail convoy transporting 49 t of liquefied propane derailed, for an undetermined reason, as the train was entering into a marshalling yard to change locomotives. Fire-fighters immediately set up a safety perimeter and evacuated 2 neighbouring homes. At the same time, analyses of the explosibility measures yielded a negative outcome. Rail traffic was considerably slowed for 90 minutes. That night, the railcars left on the track continued to be moved. The next day, 500 neighbouring residents were evacuated within a radius of 230 m prior to proceeding with transfer operations on the propane railcar (lasting from 6 am until 9:15 pm), despite the fact that the car showed no signs of leaking. A specialised subcontractor transferred gas from the car into a tank for subsequent lifting. At the conclusion of this operation, the residents were allowed back home. A major logistical effort was deployed in order to manage the evacuation.

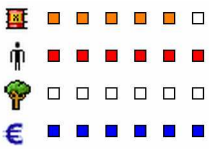


ARIA 21199 – 03/10/2001 - 13 - MIRAMAS

49.20 - Freight rail transport

During manoeuvres that took place around 3:40 am at a marshalling yard, the buffer on a flatbed car standing just after a track switch hit, at the level of its side recovery valve, a railcar transporting 48 t of liquefied ammonia (NH_3) stored at 7 bar. The associated pipeline was twisted due to the shock, forming a crack at the pipeline/tank junction and an ensuing NH_3 leak. The local prefecture activated the external emergency plan and a crisis unit was assembled around 8 am. A 1,500-m safety perimeter was set up and 400 neighbouring residents were ordered to remain indoors.

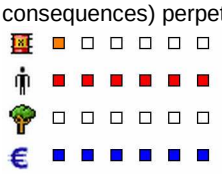
Special resources for dealing with toxic risks were requisitioned from a nearby firm while awaiting for the product owners to arrive at the scene. Train traffic was halted. The toxic cloud spread with the wind (at 8-10 m/s) to a distance 700 m from the car in a relatively isolated plain. The attempt to transfer the liquefied gas into another car (which arrived 8 hours after) failed due to deterioration of the side recovery valve fixture, which prevented connecting the hose. The leak eventually stopped on its own the next morning. The 48 t of product were dispersed into the atmosphere, as well as into local water sources (streams, and the water table): a portion of this water was actually diluted in the water curtain deployed as a protective measure. Fire-fighters, backed up by specialised units, degassed the entire railcar. The external emergency plan was lifted around 8 am. No injuries were reported.



ARIA 26597 – 18/02/2004 - IRAN - NEISHABOUR

49.2 - Freight rail transport

A 48-car train stopped in a station broke free of its locomotive around 4 am (local time). The convoy contained: 17 railcars carrying sulphur, 6 with gasoline, 7 with fertiliser, and 10 with cotton. The train overturned a bit further down the track and caught fire. At 9:37 am, as emergency responders considered the blaze to be under control, an explosion evaluated at 180 t of TNT equivalent and heard 75 km away formed a crater 20-25 m deep and 150 m in diameter. At the same time, the Teheran Geophysical Institute recorded an earthquake measuring 3.6 on the Richter scale, yet the two events would not have been directly related. The toll was tremendous: 289 deaths, including 150 civil servants, fire-fighters, rail workers and police officers, with the other 139 fatalities being village residents and bystanders, plus another 460 injured. The 2 villages of Hachémabad and Dehno were totally destroyed and 4 neighbouring municipalities sustained considerable damage. According to the Transport Ministry, this accident would have been caused by human error committed in the station and, perhaps, an act of sabotage (with disastrous consequences) perpetrated by a disgruntled employee.

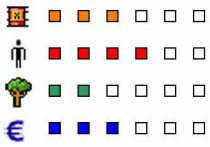


ARIA 26980 – 22/04/2004 - NORTH KOREA - RYONGCHON

49.20 - Freight rail transport

According to a provisional report, the explosion of two trains in a station led to more than 161 fatalities, including 76 children, and at least 1,300 injured. The explosion was due to a collision, during a station manoeuvre between railcars transporting oil and other trains filled with ammonium nitrate, that would have caused a transmission tower to fall, followed by a short circuit. All buildings within a 500-m radius,

including a school, were razed. Some 2,000 apartments were destroyed, along with 129 public buildings. According to initial estimates, total damage amounted to €300 M.



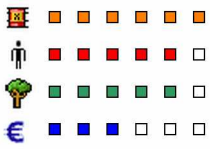
ARIA 32592 – 27/11/2006 - ALGERIA - AZZABA

49.20 - Freight rail transport

A freight train, travelling between Skikda and Annaba, derailed at 1:02 pm in the eastern suburb of Azzaba, where the track had been raised. The locomotive, pulling 16 cars (11 of which containing fuel), suddenly tipped over causing 8 tankers to overturn (7 diesel and 1 gasoline), and a spill of 420 m³ of hydrocarbons (HC).

Major soil vibrations were felt, leading to widespread panic among local residents. The civil protection services evacuated residents from the adjacent zone and established a safety perimeter. A large proportion of the HC released wound up entering sewer pipe inlets, only to exit 800 m further downstream into a river through an outlet near a densely-populated district. Around 2 pm, a fire broke out at the boundary of the main canal, triggering an explosion that spread to the sewers (domino effect). Given the strong pressure created, manholes were unearthed and sent flying, at times more than 15 m into the air, killing a child and heavily damaging the pavement and all cars on it.

Given the extent of this accident, emergency responders were required to protect individuals and property close to the derailment site while at the same time containing the fire and pumping the fuel spread into the sewer system as fast as possible. At 4:30 pm, a petrochemical platform sent a backup contingent from among its reserve forces. Civil and military authorities from the local Wilaya administration as well as the CEO of the rail transport company arrived on the scene. Track was mangled over nearly a 400-m stretch and had to be cut away. Due to the risk of igniting the HC saturating the soils, the rail link, critical to the transport of fuels between Annaba and Souk Ahras, could only be restored around 4 pm the next day following issuance of a permit to use a blowtorch within a given perimeter. The contaminated surface area, covered by sand to absorb the HC, was stripped down to a certain depth. The fuel had also partially polluted the Fergoug Dam water, imposing as a precautionary measure the interruption in drinking water supply to residents of both Mohammadia and Sig. An analysis of raw water samples nonetheless yielded negative results, which were subsequently confirmed by analyses of treated water samples. One death and 4 injuries, one of which serious, were reported. The national gendarmerie investigation assigned responsibility of the accident on a number of executives working for the rail operator, citing them for negligence in maintaining the railway, given its age, and for failure to respect safety criteria, such as tank filling. For its part, the transport company accused the Ramdane-Djamel station's Head of Operations, as well as the train conductor and ticket agent, who would be brought before a disciplinary panel.

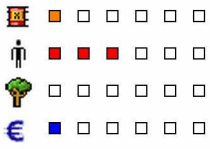


ARIA 33274 – 16/07/2007 - UKRAINE

49.20 - Freight rail transport

A freight train travelling between Kazakhstan and Poland transporting 700 t of yellow phosphorus, which is a highly toxic product and extremely flammable when in contact with oxygen, derailed in Western Ukraine: 15 tanks were overturned and 6 of them ignited, creating a white toxic cloud that covered an 86-km² land area. Emergency responders controlled the blaze in 5 hours, then cooled the phosphorus and used a combination of foam and sand to prevent any new fire outbreaks. This information was broadcast to the 11,000 residents of the zone, creating some commotion and panic; in all, 900 were evacuated. Wearing gas masks and staying indoors were initially advised by the authorities. On 18 July, the government began reassuring the local population with announcements indicating that the zone was no longer polluted. The railway was repaired, tank leaks plugged, railcars placed upright, and the convoy sent back on 26 July towards Kazakhstan at low speed, without stopping, in bypassing big cities and accompanies by 2 fire-protection trains. The polluted parcels were cleaned and a dike built adjacent to the site in order to protect a village and collect the polluted water. Some 900 kg of crystallised phosphorus were recovered at the accident site. On 3 August, phosphorus residue left onsite spontaneously ignited.

174 people, including 46 children and 14 responders, were intoxicated and had to be hospitalised. According to the regional branch of the Ministry of Emergency Situations, analyses of the air, soil and water both at the accident site and in the vicinity revealed a rise in the phosphorus rate "two to three times higher than the standard", but just at the epicentre, i.e. covering an area "roughly 1 km²". For its part, the Environment Ministry confirmed that the rate of phosphorus in air was tens of times above standards (3.5 mg/m³ vs. 0.15 mg/m³) in 2 villages, Angelivka and Lisne, but no water or soil pollution was detected. The losses incurred by farming activities were estimated at 109,000 dollars, and the Ukrainian government freed up 2.8 million dollars to eliminate all after effects of the disaster; of this sum, 2.4 million were allocated for social services to protect the children and single mothers. The cause of this accident is still not known, but an investigation was undertaken based on the charge of "railway operating rule violations".



ARIA 35530 – 12/11/2008 - 64 - ARTIX

49.20 - Freight rail transport

Around 9 am, after unloading a convoy of 26 railcars (5 of which were carrying monomer vinyl acetate, 11 had acetic acid and the other 10 were rolling empty but not yet degassed of methanol) inside a chemical plant in the direction of the marshalling yard, 5 of the cars derailed. Two of these cars were transporting 80,000 litres each of monomer vinyl acetate (MVA, a non-toxic yet highly flammable product) overturned below the 5-m high embankment, causing two manholes to open and their contents to spill into the soil.

The gendarmerie set up a 500-m safety perimeter and evacuated 16 local residents; rail traffic and road traffic on the D817 highway were halted; the passenger rail station was also evacuated. Over 70 fire-fighters were called to the scene and laid a 1,000-m² foam blanket under the cars; they were only able to close one of the two manholes, then installed both a buffer storage to recover the MVA still flowing and a dam to prevent pollution from reaching the AULOUZE River. At 4:45 pm, the safety perimeter was scaled back to 100 m and rail traffic resumed; train speed however was reduced until the intervention was over. Up to the morning of 15 November, the derailed cars were emptied, inerted and placed upright using two 200 t and 90 t cranes. During these operations, the emergency response team set up powder nozzles around the tanks receiving these transferred products and regularly replaced the foam blanket. The chemical site which sent the convoy emptied the cars on 15 November and the polluted soil on 17 November. The responders patrolled the zone and measured the explosibility potential

until the morning of 16 November: the 16 evacuated residents were allowed to return home. The classified facilities inspectorate and an elected official made a site visit.
A fire-fighter who sustained an injury to his right thumb and received foam projections in the eye, was transported to the hospital. Since MVA is 90% biodegradable within 14 days, aquatic pollution could be avoided and soil pollution limited. Rail traffic was stopped for 7 hrs, 45 min and the highway was closed for 5 hrs, 10 min.
The accident occurred on a turn known to be dangerous, hence the train's reduced speed. According to the rail network operator, this derailment was caused by a technical flaw of the system; embankment sliding due to heavy rains over the previous 2 weeks was cited.

ARIA 37598 – 24/11/2009 - 64 - ORTHEZ

49.20 - Freight rail transport

The last 2 tanker cars, nos. 26 and 27, of a freight train transporting hazardous substances derailed around 7 pm in the vicinity of the ORTHEZ rail station; car no. 26 carrying 45 t of propane was on flipped its side below the track, while a liquid-phase leak was spilling onto the pipe, which subsequently ruptured. A 100-m safety perimeter was set up and the personnel and patients at both a hospital 50 m away and a clinic 200 m away were kept indoors (233 individuals, 190 of whom were patients). Rail traffic was halted in both directions, and electrical supply of the catenaries was cut. Two trains transporting 65 passengers were also blocked; travellers were placed under the authority of emergency services, and some of them were transported to their destination by coach. Fire-fighters installed a 50-cm foam blanket underneath the overturned railcar and plugged the LPG leak by 8 pm; no presence of gas was detected thereafter. The authorities requisitioned a large-capacity flare device and broadcast information messages to local residents; a 120-t rail crane was shipped from DIJON. Passenger traffic between TARBES and DAX was transferred onto coaches. On 25 November, car no. 27 was placed back on the track and evacuated by 10:30 pm. Using the flare to burn gas from the overturned car began on 26 November at 12:30 pm under the protection of fire hoses, including nozzle guns, and ended on 28 November at 8:15 am. The car tanker was then inerted with nitrogen before being placed upright with the help of the 120 t crane after disassembling the catenaries. Rail traffic was reopened on 30 November once the track had been repaired over a roughly 50-m stretch and the catenaries restored to good working order.

ARIA 39500 – 22/12/2010 - 57 - WOIPPY

49.20 - Freight rail transport

At around 2:10 pm in a marshalling yard, a 4-railcar convoy carrying coal collided with and damaged a group of 4 railcars carrying chlorine (Cl_2), which were nearly empty, not yet degassed and at a full stop. Under this shock, 2 tanker cars overlapped one another. A bogie from the first was torn off while the second derailed.
The station's internal emergency plan was activated. A safety perimeter encompassing the split siding was cordoned off. Notified at 2:15 pm, the first responders arrived at the scene at 2:35 pm. After visual confirmation that no leak was present, the car lifting operation was authorised. The station operator informed the prefecture at 8:45 pm upon the advice of an expert with the freight shipping company, who considered that the risk may have been underestimated by the fire-fighters. Called back to the site, the fire-fighting team confirmed their initial conclusions. The safety perimeter was reduced to 4 tracks.
On the morning of 23 December, the quantity of Cl_2 contained in each railcar was evaluated at 1.6 t (1.5 t liquid and 53 m^3 of gas). Since the safety report of the yard had not accounted for the dispersion of several tonnes of Cl_2, a modelling request was submitted to the emergency situation support unit of a public agency. The distances of both irreversible effects and lethal effects were estimated at either 1,000 m and 350 m under normal situations (neutral weather conditions and a 5 m/s wind speed) or 3,000 m and 500 m under unfavourable conditions (very stable and a 3 m/s wind speed). A shopping centre was located just 1.2 km from the overlapping cars.
On 23 December at 3 pm, the prefecture assembled the fire-fighters, rail operator, shipping company and classified facilities inspectorate in order to specify the intervention conditions. With the option of onsite drainage rejected, it was decided to secure the overlapping tanker car with a crane at the time of evacuating the undamaged cars via the track. The overlapping tanker car could then be placed on the ground prior to cutting out the bogies with a blowtorch and removing the tank via a flatbed car to a degassing facility. Thermocouples used during the cutting operation would serve to monitor the temperature, given that the steel was capable of combusting when placed in contact with the Cl_2 in the neighbourhood of 120°C. These sensitive ope rations were held at night.
The accident was caused by the mistaken order to send the 4 coal cars; the automatic braking system failed. Regulations regarding the rail transport of hazardous substances had been modified shortly beforehand in the aim of preventing this very type of accident. The damaged cars had still not been fitted with anti-overlapping devices to protect the back of the cars (temporary period).
The safety report produced for this yard in 2009 had been followed in April 2010 by a compliance request pursuant to the Ministerial decree issued on 18 February, 2010 that had yet to be implemented. The following month, 2 other accidents occurred at this same vital station (ARIA 39508 and 39703) due to the volume of rail traffic into and out of Germany.