Rupture of a pipeline within an underground hydrocarbon storage facility in saline cavities
1st May 2010
Manosque (Alpes-de-Haute-Provence) France

THE FACILITIES INVOLVED

The site:
The event at the origin of this accident involves a storage site devoted to petroleum products in saline cavities located within the towns of Manosque and Dauphin, right in the heart of the Lubéron Natural Park. These installations were connected with the main petrochemical plants of Fos-Berre and Lavéra by a network of pipelines.

Characteristics of the installations:
Since 1969, 7.5 million m³ of petroleum products, including 350,000 m³ of naphtha*, were capable of being stored in 26 large cavities 300 to 400 m high excavated into geological strata within salt formations.
These installations were not subjected to the regulations applicable to classified facilities, but instead to the Mining Code and SEVESO Directive.

* Raw material used by chemical plants in the synthesis of plastics.
Naphtha, which is a highly volatile product, carries risks of ignition and explosion when placed in contact with air.

Releases
Pipe network / pipeline
Hydrocarbons / naphtha
Corrosion
Pollution clean-up
Offset retention

Geographic location of the site and the area's primary watercourses (all rights reserved)
The site's subwatershed converges towards a single outfall. A retention basin (R1008) was set up to recover hydrocarbons or brine in case of an incident. This retention basin was equipped with hydrocarbon and salinity detectors.
The infrastructure involved:
The infrastructure was an underground section of pipeline connecting a pumping station to a saline cavity (denoted ER 151 on the drawing), featuring the following primary characteristics:

- Diameter (DN): 500 mm;
- Maximum service pressure: 66 bar;
- Pressure at the time of the accident: 62 bar;
- Underground depth: 2 m;
- Component material: Steel (type: API 5L X42);
- Nominal tube thickness: 7 mm;
- Product being transported at the time of the accident: naphtha, whose flash point is on the order of 41°C. The Lower Flammable Limit is 0.6% to 0.8%, while the Upper Flammable Limit is 6%-7%. Moreover, the vapour pressure equals 0.3 kPa at 20°C.

This pipeline was tested at 110% of its maximum service pressure in 2003. A regularly-monitored cathodic protection system was implemented to ensure its corrosion resistance.
THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

Chronology of events:

1st May:
7:20 pm: Rupture of the pipeline transporting the naphtha.
A loud noise followed by a sudden pressure drop was observed at the level of the pumping station.
7:23 pm: The shift foreman stopped the ongoing naphtha injection process.
7:25 pm: Notification was sent to the on-call security detail.
7:30 pm: The Internal Emergency Plan was activated.
7:43 pm: The leak was located; naphtha was flowing on the road and into the stream for ultimate discharge at the outlet.
7:45 pm: End of the closing period of the motorised gate valves from the 5,000-m³ retention basin (R1008), i.e. 25 minutes after the pipeline break.
The hydrocarbon detection alarms on the retention basin were triggered.
The presence of naphtha was observed in one of the cells upstream of the basin.
Access to the site was blocked subsequent to explosibility measurements.
8:30 pm: The local fire department was called.
8:50 pm: The presence of naphtha downstream of retention basin R1008, combined with the construction of absorption dams on the AUSSELET River. A call was placed to the Prefecture as well as to the agency policing the mines.
9:00 pm: Arrival of fire-fighters at the scene.
9:48 pm: An onsite visit by the Deputy Prefect.
10:05 pm: Presence of naphtha in the "Patte d'Oie" hamlet(*) 2 km downstream of retention basin R1008, which was located in the vicinity of residential dwellings.
The Prefecture initiated the External Emergency Plan; 75 fire-fighters were deployed, along with a chemical emergency squad, a specialised pollution cleanup unit and some 20 gendarme officers.
10:14 pm: A call was made to the administrative agencies responsible for dealing with health issues, given the fact that drinking water extraction zones had been set up in neighbouring municipalities.
10:20 pm: Following the runaway of a vehicle engine that penetrated into the flammable gas cloud at "Patte d'Oie"(*), all parties involved were reminded of the strict necessity to respect the (1-km) safety perimeter.
Absorption dams were installed at "Patte d'Oie".
10:30 pm: The request was filed to set up a dam on the CD5 local road and evacuate the first group of dwellings.
10:50 pm: Request filed to install a foam blanket (400 litres of emulsifier to be poured onto the R1008 basin surface).

(*) See map on p.1.
10:52 pm: Assessment of the behaviour of naphtha, issued by the Fire Department Chief: "Heavy vapours, absence of wind, relatively low outside temperature. The naphtha vapours for the most part remained confined to the streambed."
11:00 pm: Evacuation of the villages of Dauphin(*) and St Maimé(*); 15 people assigned from 5 gendarmerie brigades, along with 70 fire-fighters, were dispatched for this mission.

11:32 pm: The foam blanket was poured onto the retention basin.

The placement of additional dams on the LARGUE River(*) was targeted at its confluence with the DURANCE(*).

Explosibility measurements were being constantly taken from the R1008 basin extending to the LARGUE(*).

**2nd May:**

12:20 am: Use of mobile pumping facilities, then stationary pumps in order to recover naphtha from within the basin. A specialised subcontractor wound up pumping 150 m³ of naphtha.

3:00 am: After another campaign of explosibility measurements at “Patte d’Oie”(*), the rescue team installed a water curtain.

3:45 am: Local residents were allowed back to their homes (except for 5 dwellings).

4:00 am: The majority of residents had returned home, yet water extraction in 3 municipalities was suspended.

6:00 am: The response teams onsite were replaced by fresh personnel.

10:35 am: The Lower Flammability Limit recorded a 0% reading both in the R1008 basin and at “Patte d’Oie”(*).

1:15 pm: Interviews were given with television stations (France 3 and M6).

2:30 pm: In conjunction with the mining police agency, recommended measures were determined (preconditions for resuming operations and environmental measures).

4:00 pm: Information was communicated to residents of Dauphin(*) and St Maimé(*). A 0% Lower Flammability Limit was recorded at all measured points.

6:30 pm: The External Emergency Plan was lifted.

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(*) See map on p.1.
Consequences of this accident:
This accident generated a range of consequences, including:

Hazardous substances released:
An estimated volume of 400 m$^3$ of naphtha flowed out through the pipeline opening towards the 5,000 m$^3$ capacity retention basin situated several hundred metres downstream, on a section with a 20-m elevation difference. 200 m$^3$ of product escaped from this basin via 2 gate valves that had been left open for over 25 minutes. The quantity of naphtha evaporated during the accident is not known. The cloud shape had never been modelled.

Human and social consequences:
During the personnel evacuation step, the site caretaker felt faint and had to be taken to hospital. While rescue teams were onsite, 2 fire-fighters were overcome by naphtha fumes and had to be placed on oxygen. A 1-km safety perimeter was introduced, and 282 residents from 2 different towns were evacuated at around 5 am. Upon returning to their homes, local residents were prohibited from using tap water upon the recommendation of authorities. Since the water supply was not sufficient to meet the needs of residents, 168 cases of bottled water were purchased and distributed by the town hall of Dauphin. For the other municipalities, water supply wells were inspected; no pollution however was noted.

Environmental consequences:
Impacts on both flora and fauna within exceptional protected habitats were observed: dead mammals, amphibians and invertebrates.

![Fatal impacts on toads and foxes](image)

Fatal impacts on toads and foxes (all rights reserved)

Naphtha flowed over a 5-km distance along both the AUSSELET and LARGUE Rivers. At the spot where the leak occurred, 1,500 m$^2$ of ground were polluted over depths ranging from 3 to 4 m.

Economic consequences:
The site operator allocated €7 million towards modifying and inspecting the pipe network (covering more than 8 km).

The European scale of industrial accidents
By applying the rating rules applicable to the 18 parameters of the scale officially adopted in February 1994 by the Member States’ Competent Authority Committee for implementing the 'SEVESO' directive on handling hazardous substances, and in light of information available, this accident can be characterised by the four following indices:

- Dangerous materials released
- Human and social consequences
- Environmental consequences
- Economic consequences
The parameters composing these indices and their corresponding rating protocol are available from the following Website: http://www.aria.developpement-durable.gouv.fr.

The "hazardous substances released" index was scored a "3" as a result of the 400 m³ of naphtha that spilled out subsequent to the pipeline rupture.

The "human and social consequences" index was assigned a "3" for causing the evacuation of 282 residents for a period lasting more than 5 hours.

The "environmental consequences" index was set equal to "3" due to the extensive flow of product over a 5-km distance along the AUSSELET and LARGUE Rivers.

The "economic consequences" index could not be rated given the lack of any information relative to this indicator.

THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THIS ACCIDENT

The pipeline was excavated. A break was observed over a 3-m length at the level of the lower generatrix line at the 6 o’clock position:

Following an expert appraisal, a laboratory concluded in June 2010 that the rupture was caused by pitting corrosion that had developed underneath a hardened deposit at the tube bottom.

The positioning of this corroded zone, aligned with the lower generatrix, would have been correlated with the circulation of saltwater, which is denser than naphtha within the pipe.
The hard deposit was composed of a mix of hydroxide and iron oxide, and included traces on the surface of: oxygen, sulphur, and chlorine. The chlorine, present in the form of chloride, contributed to the loss of pipe wall thickness by means of a corrosion mechanism involving differential aeration.

This loss of thickness on the lower generatrix created a zone of less mechanical strength, which in turn facilitated the line's rupture, in propagating its tear over a length exceeding 3 m.

Non-destructive controls (NDC) were performed on selected points of the pipeline section in order to localise other critical zones over the larger segment; no loss of thickness was observed elsewhere. Tests conducted to determine the mechanical characteristics of the tube's component steel revealed no anomaly.

**ACTIONS TAKEN**

**Measures adopted following the event:**

The operator devised an initial series of corrective measures on the retention basin (R1008), in addition to focusing on the site's pipeline network. The External Emergency Plan was modified for the purpose of incorporating feedback from the May 1st event.

**Retention basin:**

Several measures were introduced:

- Reconfiguration of the R1008 retention basin and installation of new automated mechanisms: motorised gate valves with remote controls and control room relays, servo-control of these devices to pressure drop detectors;
- Verification of the state of repair and seal of these valves;
- Improvement of upstream (early) detection and increased number of hydrocarbon detectors.

**Pipelines:**

Following the accident and in compliance with a Prefectural order, the mine police requested the operator to lower the service pressure of all pipelines throughout the site. As a result, the operating pressure dropped from 65 bar to 45 bar. The pipeline section isolation devices to be used in the event of a leak were also modified.

**Environmental impact monitoring:**

In August 2010, a consultant performed a diagnostic assessment of site soil quality based on a campaign of several samples of:

- water and sediments on various streams and watercourses,
- soils at various depths.

The results of this assessment revealed soil pollution at the level of the leak with high concentrations of benzene, toluene and volatile hydrocarbons. Since these compounds are biodegradable, the consultant proposed a number of in situ solutions to treat the soil and water table. The relevance of these potential solutions was examined by the inspectorate to determine the remediation works required, pollution cleanup targets as well as the execution schedule.

Regarding impacts on flora and fauna, a specialised laboratory confirmed in a report dated 30 November 2010 that a severe impact had occurred in the aquatic environment, though the consultant had the impression that flora and fauna tended to re-establish their populations rather quickly despite the deteriorated habitat.

Moreover, it did not appear necessary to scour the AUSSELET River, as the flora and fauna were observed to return to normal conditions shortly thereafter.

These conclusions were entirely consistent with the prospection reports produced by other consultants in June and October 2010.

**Monitoring of service provision for the site’s pipeline network:**

The operator studied the technical feasibility of running an instrumented scraper through its pipe network. The focus of such a strategy was to verify the possibility of modifying the current pipe alignment in order to operate an instrumented tool capable of performing a thorough inspection of pipe conditions.

Towards this end, the operator submitted to the inspectorate in November 2010 a report whose provisional conclusions offered several contributions, namely:

- Scraping and inspection of collection pipelines by means of an instrumented piston of various sections at the Manosque site was feasible.
• The entire series of preliminary modifications necessitated a works schedule on the order of 10 months prior to initiating the inspection phase using an instrumented piston.
• The phase of scraping and inspection carried with it a timetable that could not be compressed to less than 3 months, as evaluated without taking into account either the availability of supplier(s) for this specific phase or the operating constraints.

The cost of the corresponding operations has been estimated at over €7 million.

A Prefectural decree adopted in June 23, 2011 assigned the calendar of tasks and measures to be implemented in order to both manage additional pipeline risks and define the site retention system. This decree also specifies the protocols for cleaning up polluted ground as well as for restoring ecological monitoring of the zone affected by the accident.

LESSONS LEARNT

Following this event, the operator provided an assessment of the main positive features and areas requiring improvement. Among the positives, the effective response of the crisis unit was cited in addition to the constructive relationship developed with the agency responsible for policing the mines.

Regarding areas slated for improvement, the operator indicated the need to be prepared with:
• individual protective gear in adequate supply (cartridge respirators);
• a stock of explosimeters, flashlights and radios that meet ATEX Directive specifications, as well as disposable work outfits;
• resources on hand for constructing road dams;
• a reserve of non-perishable food and water onsite;
• a fleet of vehicles capable of making emergency stops and equipped with a fire control pan.

Generally speaking, accident statistics indicate that human intervention on leaks fed by a flammable liquid may be quite hazardous. An adequate safety perimeter must be quickly established around the leak zone. In the case of this accident, the perimeter was spread over a 1-km radius circle. Naphtha vapours are capable of forming explosive mixes when in contact with air or cause fires by accumulating electrostatic charges (Klinkenberg experiment); consequently, it is recommended to limit the product's evaporation surface area to the greatest extent possible.

In Manosque, several techniques were used:
• construction of floating dams and use of haystacks on watercourses to limit the naphtha flow;
• installation of a foam blanket on the retention basin to reduce the rate of product vaporization;
• a 1-km safety perimeter in order to mitigate ignition sources.

Explosibility measurements and hotspot prevention deserve considerable attention and precautions, as a simple cell phone or piece of camera equipment is capable of triggering combustion. Pockets of flammable gas can arise within confined spaces, and explosibility measurements must be conducted in such spaces without underestimating the risk of explosion.

The emergency plan serves as a benchmark used for the various actors during emergency situations. This plan includes the intervention procedures previously agreed upon between the operator, fire-fighters and gendarmerie or police that clearly define the roles and protocols for each actor's intervention: valve shutoff, safety perimeter designation, assistance provided the population, and confinement phase management.

Beyond the existence of a regularly-tested emergency plan adapted to the various types of fluid transported through the pipeline, emergency response management relies on effective coordination between the intervention services involved (i.e. police, gendarmerie, fire-fighters) and the operators. Relief for victims, installation of a command and control centre shared among all services, adjustment of the safety perimeter and communications management constitute the key elements of any such plan.

Other accidents involving transport pipelines:
ARIA 168: Accident at Rosteig (France), on 28 July 1989,
ARIA 35176: Accident at Appomattox in Virginia (United States), on 14 September 2008,
ARIA 36654: Accident at La Plaine de la Crau (France), on 18 August 2009…