Explosion of a single-family dwelling due to underground hydrocarbon pollution

4 August, 1990

Le Petit-Couronne [Seine-Maritime]

France

Explosion
Hazardous release
Refinery
Buried pipelines
Hydrocarbons
Pollution (groundwater, soils)
External property damage
Corrosion
Pollution clean-up

THE FACILITIES INVOLVED

In 1990, the refinery, with an annual treatment capacity of 7.5 million tonnes, was employing a staff of 700 on the Petit-Couronne site, along the Seine River in Rouen's southern suburbs. The site also contained a storage yard with a capacity of 2 million m³ of liquid hydrocarbons as well as several tens of kilometres of buried pipelines. The facility is located in the vicinity of urbanised zones within the municipality of Le Petit-Couronne.

This same zone also accommodates a hydrocarbon transport pipeline belonging to another industrial operator.

THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

The accident:

- End of 1985: Hydrocarbon traces were detected in water sampled on both of the drinking water catchments present in Le Petit-Couronne.
- June 1986: Due to the smell of hydrocarbons, water supply intake from the catchments was suspended.
- October 1986: Investigations conducted in May 1986 by the various actors in the area's water supply services, including the inspection authorities for classified facilities, did not allow formally identifying the pollution source. Given the refinery's location immediately adjacent to water catchment zones, a complaint was filed against the refinery by one of the water supply operators as well as by the local water distribution authority. A legal expert was assigned the tasks of: identifying both the polluter and pollutant, determining the geographic range of the subsequent effects, proposing decontamination solutions, and lastly ensuring the resumption of pumping activities.
- 1987-1990: Widespread campaigns of boreholes, extraction and analyses were performed. Various types of pollutants were successively identified: a mix of 30% light hydrocarbons and 70% heavy hydrocarbons at the end of 1986, vs. the inverse proportion (70% light, including alkanes, and 30% heavy) in 1990.
- In conjunction with these investigations, a study was commissioned to a specialised expert. Four of the 15 samples extracted indicated strong contamination of the water table; moreover, an approximate mapping of the likely extension to the polluted zone was produced (see Map 1). At this stage however, the study was still not able to adequately estimate the quantity of hydrocarbons to be eliminated.
- Beginning of 1990: A significant deterioration in the situation was noted by an observation of hydrocarbon odours emanating in some districts of Le Petit-Couronne.
- May 1990: During a meeting presided by the Upper Normandy Prefect's Cabinet Director, a monitoring mechanism was implemented in order to ensure protection of the exposed population. The mechanism called for: an inventory of all high-risk premises, regular explosibility measurements by the emergency response team, and (with assistance from the refinery operator) the installation of two additional piezometers along with a specific pumping campaign.
- July 1990: The legal expert's report was submitted to the Prefecture's agencies; its conclusion assigned liability to the refinery.

On the basis of recommendations issued by this same legal expert relative to the subsoil, a supplemental Prefectural order was enacted on July 4, 1990 imposing that the refinery operator implement the following measures:

- permanent pumping of groundwater at a high enough rate to create a cone of depression limiting propagation to the previously identified zone;
- periodic monitoring by means of sampling outside the targeted zone.

▪ At the beginning of summer 1990, hydrocarbon odours were accumulating in Le Petit-Couronne. Monitoring records revealed the presence of significant contents in both the sewer and drainage networks. The classified facilities inspectors proposed to the Prefect an emergency shutdown procedure requiring the refinery to monitor hydrocarbon contents within both these networks and provide for ventilation, if necessary, in order to prevent hydrocarbon content from reaching the lower explosibility limit.

▪ August 4, 1990: A single-family dwelling had been unoccupied for two weeks. Upon returning at 1 am, the owner by drawing hot water from a tap caused the water heater installed in the basement to turn on. The residence exploded following ignition of the hydrocarbon vapours that had accumulated during the homeowner's absence.

Over the next three days, the sector was under constant surveillance by local fire-fighters; in addition, it was decided to temporarily evacuate a number of dwellings within this residential zone. Following an inventory of the higher-risk premises, air extractors were placed at points considered to be particularly sensitive.

Consequences of the accident:

Since 1986, the extraction of drinking water from the catchment has been interrupted in the contaminated wells.

In light of the analyses conducted on the 15 boreholes drilled in the zone, the surface area of the polluted water table was estimated in 1989 at approximately 100 ha. During their migration to the water table surface, the hydrocarbons would have been trapped in the ground over a height of roughly 1 m (aquifer recovery zone). Even though this pollution was not exerting a significant impact on the neighbouring residents, the situation quickly worsened beginning in 1989 with the outward filtration of hydrocarbon vapours in some districts of Le Petit-Couronne; these were composed mainly of BTEX (i.e. benzene, toluene, ethylbenzene, xylene), with benzene content being particularly noteworthy. During the spring of 1989, many complaints were filed as a result of odours emanating in a child care facility and a cultural centre; then, during August 1990, these vapour releases caused the explosion described above in the house basement. The homeowner sustained just a slight concussion, but the house was entirely destroyed.

Without waiting for all the administrative procedures to be completed, the refinery operator settled for damages incurred by third parties; this settlement entailed: purchasing the land and destroyed house as well as the neighbouring property, payout of 18 million francs (MF) in 1991 currency to the municipality, compensation provided to the water supply catchment operator, the water distribution authority (2.8 MF, 1991) and to a retailer located near a control well (2.2 MF in 1991). The total cost of the compensation paid out and the ancillary works reached 50 MF (1991 currency).

The total quantity of hydrocarbons lost was estimated at between 15,000 and 20,000 m³, and for the premium grade fuel alone at between 10,000 and 12,000 m³.

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:

The parameters composing these indices and their corresponding rating protocol are available from the following Website: www.aria.developpement-durable.gouv.fr.

Given the estimation of inflammable hydrocarbon quantities released into the soil (total quantity of hydrocarbons lost was estimated at between 15,000 and 20,000 m³, with this figure lying between 10,000 and 12,000 m³ for the premium grade fuel alone), the "Hazardous Materials Released" parameter receives a 4 rating (parameter Q1).

A value of 2 is ascribed to the human and social consequences, corresponding to destruction of the house where the two individuals had been living (parameter H6), one of whom was slightly injured due to the blast (parameter H5).

The environmental consequences were rated at a value of 5, reflecting the pollution caused both at the soil surface and to the groundwater (parameter Env 13).

The economic consequences received a 5 rating as well as a result of the 24 MF (1991) in compensation paid out by the refinery operator plus the purchase and subsequent demolition of 2 homes (parameter € 17). The pollution clean-up works undertaken by the operator amounted to approx. 26 MF (1991), corresponding to a level 4 for parameter € 18.

THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THE ACCIDENT

Several hypotheses were initially forwarded by the various stakeholders to explain the presence of hydrocarbons:

- deliberate drainage of refinery stock during the Second World War,
- leak in an underground tank at a filling station
- a more recent leak at the refinery.

Sealing inspections on filling station tanks within the targeted zone served to refute the second hypothesis.

On August 23, 1990, a leak was identified in an underground transfer line at the refinery used to channel premium grade fuel to the highway transport station (also used in the past to transfer sulphurated diesel fuel to the storage facility), and this line was located adjacent to a hydrocarbon transport pipeline.

This line had only transported the unleaded premium grade fuel over the previous 18 months and before then a succession of products corresponding to diesel fractions (LCO fractions) and white spirit, which would thus explain the variation observed in contaminant characteristics, i.e.:

- Beginning in 1986: 30% of light hydrocarbons (white -spirit) and 70% heavy hydrocarbons (LCO),
- In 1990: 70% of light hydrocarbons, including fuels, and 30% heavy hydrocarbons (LCO).

This leak was fed each time product was transferred and caused groundwater pollution, for which the gaseous phases propagated via the city's drainage network. The owners of the destroyed dwelling had been absent for two weeks and their basement had not been ventilated, hence allowing an explosive atmosphere to form. This atmosphere was then ignited once the main water boiler burner was reactivated when hot water was drawn from the tap.

The punctured pipeline ran both aboveground and belowground. The leak was located at the level of an elbow in the descending part of the line, and this segment had always been buried. At this precise spot, the pipe setting was destroyed by hydrocarbons originating from the leak. The pipe was punctured from the outside towards the inside. The hole diameter measured 40 mm to 60 mm on the upper part and 6 mm on the lower part, since this coastal cavern-like structure features a corrosion characteristic of electrochemical dissolution[1].

According to the experts, several factors would have contributed to puncturing the pipeline, namely:

- The surrounding land was composed of clayey fill with many sharp-edged rocks (flint), some of which "imprinted" the pipe lining upon each onset of corrosion, whose penetration into the metal thickness exceeded 50% in some cases. Similarly, the pipes sat at regularly-spaced intervals on the steel rod edge, which presents a configuration capable of prematurely deteriorating the lining. On the other hand, the inside pipe surface was only mildly corroded.
- The earth removed from the zone indicated a very weak concentration of chloride along with a considerable presence of PO_4^{3-} and SO_4^{2-} ions, which significantly increase soil conductivity by conferring electrolytic attributes within humid environments.
- The steel structures located in the leak zone were exposed to highly-variable electrical environments from 1953 to 1990 as a result of the successive application of 11 cathodic protections. Electric potential measurements revealed that the punctured line as well as its neighbouring lines were influenced by the cathodic protection of lines in the vicinity, especially protection from the hydrocarbon transport pipeline masses. This situation caused an increase in the speed of corrosion at those spots where the tube was uncovered (and the setting stripped or punched by flint).

ACTIONS TAKEN

A campaign was organised to inform local residents, sewer network operators, and the various utilities involved (e.g. gas, phone) of the risks incurred both adjacent to the pipes and inside underground premises.

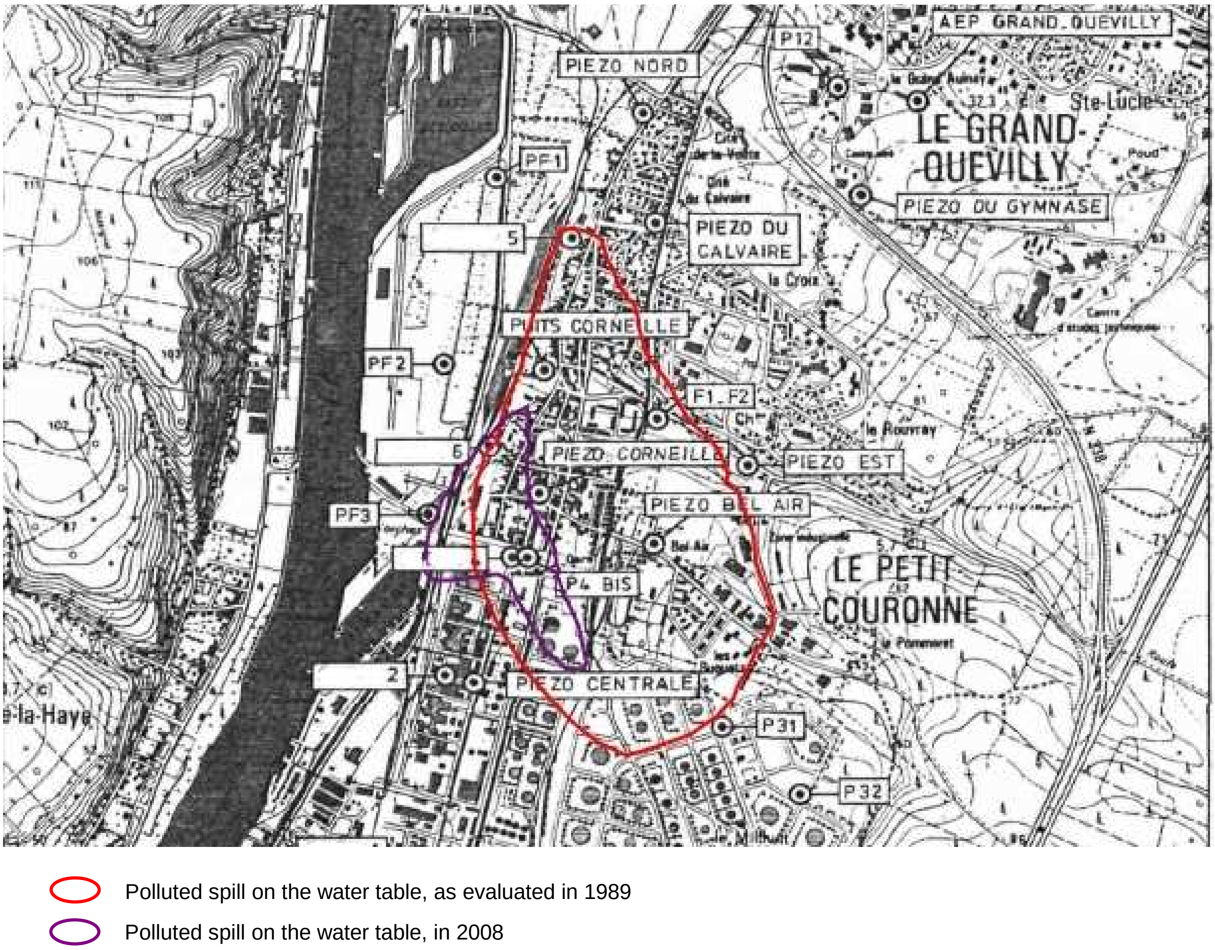
Two Prefectural orders specifying emergency measures were adopted on August 7, 1990 as a reprimand of the refinery operator's actions; they imposed:

- searching for possible causes by conducting a leak inspection of all tanks containing light products and all underground pipes at the refinery;
- allocating the resources necessary to absorb the pollution, focusing mainly on measures to prevent hydrocarbon emissions into the air, along with ventilation and installation of a monitoring network;
- implementation of measures intended to protect populations, as ultimately ordered by the City Hall, within the framework of its policing powers.

[1] Electrochemical corrosion occurs in the presence of a heterogeneity in either the metal or the surrounding environment (or both). This heterogeneity will produce a potential difference between various points of the metal; should this material be located in an environment conducive to electrolysis, piles will form and deposit in the metal mass, since they are short circuited. The anodic zones are corroded and actually disappear.

Two municipal orders were adopted on August 10; they call for extending powers, as needed, to enter private premises and to prohibit circulation near pumping points.

The leak inspection campaign continued until the end of November 1990; it encompassed 80 storage tanks and tens of kilometres of pipelines, including 16 km that had been retested. The results did not indicate the existence of any other leak. The refinery operator decided to reroute all buried pipes aboveground or into ducts feasible for inspection. Moreover, the cellars of exposed dwellings were caulked (through concreting) and the underground utility ducts sealed.



Map 1: Evolution and localisation of the polluted zone

Treatment of the liquid phase of this pollution event

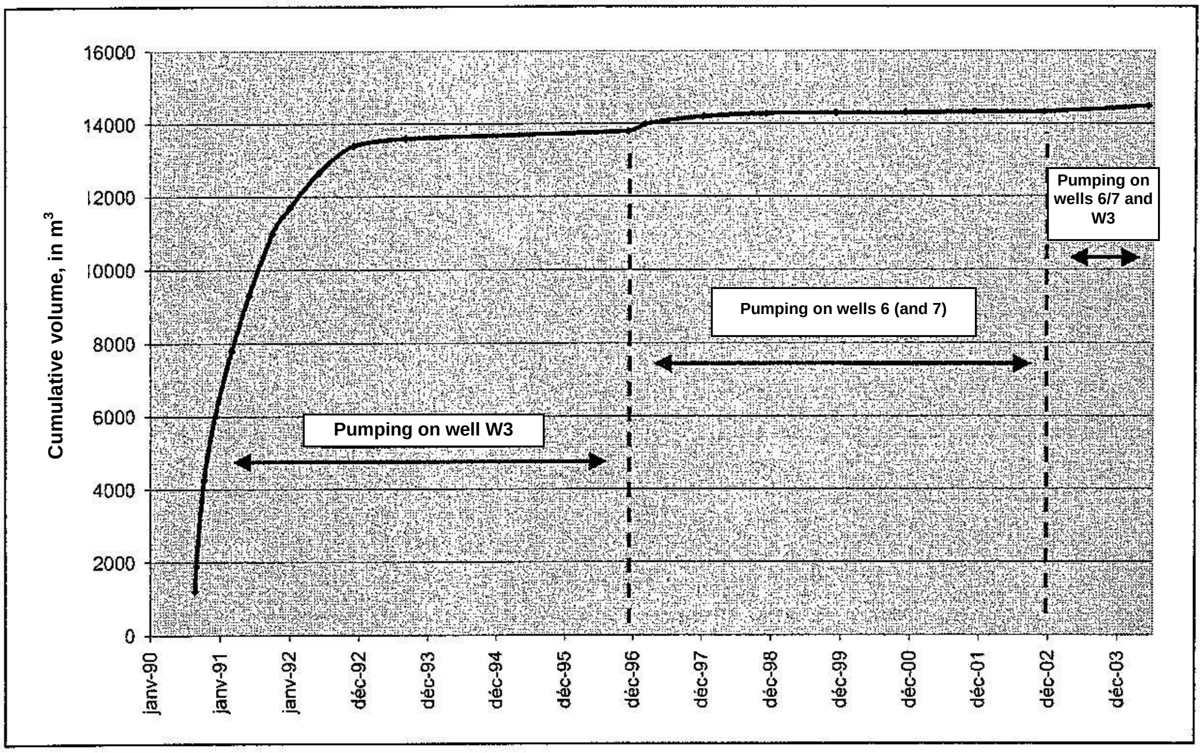
Pollution mapping, performed by analysing gases in the soil, was conducted in September 1990 and indicated that the infiltrated zone extended underneath both the refinery and the centre of the Le Petit-Couronne town, over a surface area estimated at 100 ha (see Map 1).

From 1997 to 2008, hydrocarbons were pumped into the groundwater, via the various wells located closest to the refinery, and then skimmed. As per Prefectural decree, a number of successive studies enabled determining the pumping categories and corresponding flow rates and then adapting well localisation depending on pumping efficiency and the pollution spill size / position change (Map 1). Since the heavy fraction tended to increase as of the beginning of 1994, it was decided to continue pumping until complete disappearance of the light fraction, provided pumping would remain productive on heavy residue as well. In 1998, the polluted surface area was estimated at between 40 and 55 ha. In 2005, all pumping activity as a whole allowed recovering a total hydrocarbon volume of around 14,500 m³ (Graph 2).

Treatment of the gaseous phase of this pollution event

Since the volatile phase of the hydrocarbon spill contained BTEX, and particularly the carcinogenic substance benzene, BTEX measurement campaigns have been conducted since 2003 using passive samplers inside business premises and residential dwellings of Le Petit-Couronne located above the pollution spill. In 2008, high benzene concentrations could still be detected in 5 houses, with content levels in some rooms exceeding the short-term indoor air quality guideline (published by the AFFSET Association) by as much as 2 to 8 times, therefore making it mandatory to introduce additional monitoring in all houses located within the targeted zone and identified as a potential risk.

During 2005 in a cul-de-sac, just one single-family residence revealed high benzene concentrations: these levels originated from a heating oil tank installed in the cellar, yet the possibility of a rise in the polluted layer could only be excluded once the tank had been emptied and then filled with water, along with creating natural ventilation in the cellar.



Graph 2: Cumulative total of hydrocarbons pumped over time (Source: DRIRE Agency report)

A revised pollution clean-up plan

In 2008, the quantities recovered declined and, according to estimations, 3,000 to 8 000 m³ of hydrocarbons were still present in the layer. Upon the request of the Classified Facilities Inspection office, the refinery operator proposed a new pollution clean-up plan to enable recovering floating material and capturing the gaseous phase of the pollution by means of "venting"[2], with the objective of minimising pollution after a 5-year period. This plan calls for treating both the liquid and gaseous fractions in special units and has been scheduled for implementation during the second half of 2009.

LESSONS LEARNT

Five years were required to identify the pollution source responsible for this accident; moreover, in 2009, i.e. 24 years after the fact, the pollution spill is still being treated. The consequences of this accident, which are already sizeable in terms of environmental contamination and social impact within an urbanised zone, could have reached dramatic proportions. Its occurrence highlights a number of warnings relative to both design and underground pipeline operations.

[2] Soil decontamination technique that consists of suctioning air in the soil layer located above the water table in order to extract both the volatile and some semi-volatile contaminants.

To ensure retaining initial characteristics in terms of pipeline operations and safety:

- ✓ Evaluation and acknowledgment of potential corrosion sources or factors capable of accelerating development of this phenomenon: design of the pipe and its accessories, influence of adjoining installations, soil characteristics, etc.
- ✓ Definition of the type of external pipe protection depending on soil characteristics, composition and corrosivity (depth, chemical nature, bacterial activity, eventual presence of tree roots, potential contamination by pollutants, etc.).
- ✓ To the greatest extent possible, a pipe design that eases inspection constraints: routing pipes aboveground or placing them inside a duct feasible for inspection, etc.
- ✓ Evaluation of the influence of modifications planned in the use of land crossed by the pipe (e.g. new facilities, cathodic protections) and of modifications or adaptations to the facilities or projects required to maintain pipe integrity.

To ensure quick leak detection:

- ✓ Up-to-date mapping of underground pipes, with knowledge of both the physical and chemical properties of hazardous substances being transported in the pipes, plus pipe diameter, depth, temperature and pressure.
- ✓ Implementation of technical and organisational measures to enable the quick detection of failures: detectors, accurate material inventories, maximum service pressure monitoring.
- ✓ Inspection and maintenance of underground pipes and their accessories with a periodicity adapted to the characteristics of the setting (aggressiveness, humidity, etc.), to the products being transported and to the pertinent social and environmental considerations.
- ✓ Detection of potential groundwater pollution by means of piezometric monitoring beneath the industrial platforms (relative density, type of pollutants, measurements, inspection frequency, etc.).

Other discharges on transport pipes recorded in the ARIA database for which a detailed fact sheet is available:

- ARIA 3543: Explosion of hydrocarbons within an urban drainage network, in Guadalajara (Mexico), on April 22, 1992
- ARIA 21233 / 22031: Hydrocarbon leak on a pipe in Lucciana (France), September 18, 2001 and February 9, 2002
- ARIA 23562: Leak on an effluent transport pipeline in a chemical plant, Le Havre (France), August 5-11, 2002
- ARIA 29864: Explosion of a chlorine pipeline, in Champagnier (France), May 21, 2005
- ARIA 30007: Clean break of a pipe immediately upstream of an oil terminal, Nanterre (France), December 13, 2004

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- Recommendations for managing pipeline-related risks, Belgium's Seveso Inspection Unit, June 2008.
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