UVCE
Distribution
Lead-free premium / FFO
Flanges and unions
Internal contingency plan / Special intervention plan
Victims
Aerosol

Explosion followed by fire In a hydrocarbon tank farm

October 7, 1991

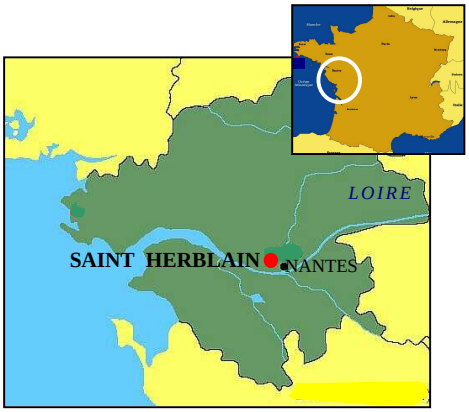
Saint Herblain – [Loire Atlantique] France

The explosion of a cloud of flammable vapours followed by a massive fire in a hydrocarbon tank farm killed a driver and seriously burned 2 company employees.

The fire generated flames up to sixty feet high

CONTEXT AND INSTALLATIONS IN QUESTION

- The tank farm, located to the west of the greater Nante area, within the *commune* of Saint Herblain, has been operated by an economic interest group since 1978. With a total capacity of 80,000 m³, it consists of 11 storage tanks ranging from 1,500 to 15,000 m³ (premium-grade gasoline, with and without lead, diesel fuel and FFO).
- This facility is part of a series of tank farms located along the Loire River over approximately 2 km, the closest being a much larger petrol station, a chemical product warehouse and a railway equipment depot. The closest industrial installations are located 400 m away and the first homes at 1,000 m. The Nantes / Saint-Nazaire rail line passes 300 m away.
- The tank farm is supplied from a quay located 125 m away. The hydrocarbons are transferred to tanker trucks by 4 loading platforms. A night watchman makes rounds after business hours.
- Ordinarily, the depot opens at 4 am; 2 employees are in charge of operations. The first trucks to arrive for loading slightly before business hours wait in an adjoining parking-relay area equipped with a service/washing station and social facilities.



Geographic location of the depot

THE ACCIDENT, ITS BEHAVIOUR AND CONSEQUENCES

The accident

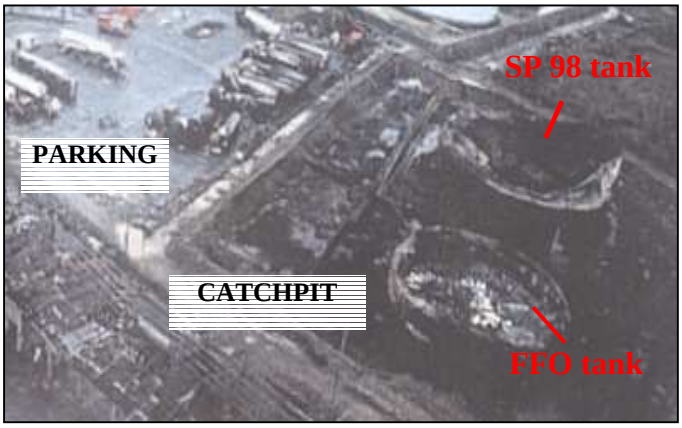
- **October 7, 1991 slightly after 4 am**: the remote-controlled opening of a valve located at the base of a 6,500 m³ tank containing 4,525 m³ of lead-free premium-grade gasoline coincides with the appearance of a cloud of fuel vapour in the sector, forming a milky-white fog. Alerted by one of the drivers, the 2 employees rushed to the scene.

- **4.20 am**: the fog that had topped the 2 m-high earthen barricade of the catchpit expanded across the parking area, covering it with a cloud approximately 1.5 m thick. The cloud, having an estimated volume of 25,000 m³, ignited 20 minutes later. The explosion, an Unconfined Vapour Cloud Explosion (UVCE), fatally injured a driver and seriously injured 2 employees. Thrown into the catchpit, these 2 employees were nevertheless able to return to the control station, attempted in vain to close the valves (the remote control system had been destroyed in the explosion) and sounded the alarm around **4.25 am**. A fire broke out at that time.

Intervention

- **4.30 am**: the Internal Contingency Plan was initiated. The emergency services arrived roughly 2 minutes later, alerted by the *Centre Opérationnel de la Direction de la Sécurité Civile 44* (CODISC) which had noticed the explosion. Police barricades were established on the access roads and rail traffic was suspended.

- Even though a water curtain was set up nearly immediately between the two tanks, the fire spread to the 2 compartments of the catchpit shared with the premium-grade gasoline where the fire started and to a 6,500 m³ tank containing 4,500 m³ of furnace fuel oil (FFO). Thick smoke was visible several tens of miles of way.



Aerial view of the tank farm

- The firemen decided to stage a "general assault" once the conditions of the depot's fire defence plan were filled. The scenario taken into account is the large compartment of the catchpit catching fire (4,340 m²); with a foam concentrate application rate of 5 l/m².min. and a flow rate of 22,000 l/min. Suppression was expected in 20 minutes.

- The flow rate available on the tank farm's boosted network was only 5,000 l/min. Despite the arrival of reinforcements with additional foam concentrate and conventional pumping means, the firemen realised that the assault could only be possible with the help of a fire-tug equipped with pumping equipment allowing them to draw directly from the Loire in a location where there was enough water under the keel at low tide (tidal fall of 8 m).

- **4.56 am**: a fire-tug from Saint-Nazaire equipped with pumps capable of delivering 12,000 l/min. was dispatched to the site.

- **5.30 am**: the flames spread to the 2 lead-free premium gasoline and FFO tanks (one of which had split open), and to the tanker trucks parked in the parking lot, posing a threat to the adjacent storage tanks. The firemen began cooling one 1,500-litre LPG tank located 30 m from the edge of the catchpit and protected a 15,000 m³ tank of premium and a 15,000 m³ tank of FFO with a water curtain.

- **6.30 am**: numerous "parasite" fires broke out (the parking and road drainage network).

- **9.55** am: the fire-tug arrives. The 195 firemen present have 80,600 l of foam concentrate (including 17,000 l made available by manufacturers located nearby) and a water flow rate of 28,000 l/min., of which 21,600 l/min. is for extinguishing purposes; twenty-two 110 mm lines are established, representing a total length of nearly 10 km.

- **11.05 am**: the "general assault" is initiated. 6,560 m² of surface area is on fire The FFO tank and its catchpit are extinguished in 35 min. The fire was completely extinguished in 72 minutes, with foam concentrate being applied at an average of 4.3 l/m².min; 50,000 litres of foam concentrate were used during the intervention.

Consequences

- The accident claimed the life of a driver and resulted in 2 employees seriously burned; 3 other drivers were slightly injured.
- The initial explosion caused serious structural damage up to 100 m and shattered windows up to 1 km away (50% at 700 m, 75% at 320 m). The explosion was equivalent to 1.8 to 3.6 t of TNT. These values are consistent with the volume of "fog" observed, evaluated at 25,000 m³, and likely to have contained 1,000 and 6,800 kg of hydrocarbons at the lower and upper explosive limits, respectively.
- Analysis of the damage highlights two factors with accentuated the violence of the explosion:
  - the aerosol may have been ignited by a gas-fired water heater in the truck washing station. The ignition in a confined space would have significantly increased the ignition energy,
  - as ignition occurred in near the parking lot, the series of repetitive obstacles created by the trucks parked diagonally may also caused the flames to accelerate and increase the overpressure generated by the blast.
- Two tanks, 15 tanker trucks, wash station and 4 cars were destroyed. The changing rooms and offices were damaged and piping deformed. The blast from the explosion pushed the fence over. The accident also damaged 3 hydrocarbon tanks in a nearby tank farm.
- Flooded by liquid or vapour phase hydrocarbons, the private waste water drainage and decantation network under the site also witnessed violent secondary explosions that destroyed manholes and sewer inlets.
- Property damage at the site was evaluated at 100 MF in 1991 (approx. 16 M€ in 1993).
- The spilt hydrocarbons, lead-free gasoline for the most part, polluted the soil to a depth of 7 m and the water table. It is estimated that 500 m³ of gasoline infiltrated the soil, irregularly distributed over 20,000 m² of land.

Camions-citernes et bac détruits lors du sinistre

European scale of industrial accidents

By applying the rating rules of the 18 parameters of the scale made official in February 1994 by the Committee of Competent Authorities of the Member States which oversees the application of the 'SEVESO' directive, the accident can be characterised by the following 4 indices, based on the information available.

The parameters that comprise these indices and the corresponding rating method are available at the following address: http://www.aria.ecologie.gouv.fr

The level 4 of the index concerning the quantity of dangerous materials released (parameter Q1) expresses the **3,600 t of lead-free premium gasoline and 3,600 t of FFO spilled.** These products are classified as petroleum derivatives (upper level: 25,000 t).

The equivalent of 1.8 to 3.6 tons of TNT is reflected by the level 3 rating of the index relative to the quantity of explosive substance which participated in the explosion (parameter Q2). As this level is below the index relative to the quantity of dangerous materials, it does not appear on the representation above.

The **death of an employee** explains the level 2 classification attained by the human and social consequences (H3).

The **2 ha of polluted land** justify the level 3 classification of the 'environmental consequences' index (Env13).

Finally, estimated property damage of **16 M€ (1993)** correspond to level 4 of the 'economic consequences' index (€15).

ORIGIN, CAUSES AND CIRCUMSTANCES OF THE ACCIDENT

- The explosive cloud could have formed from gasoline fumes according to 2 scenarios:
  - a massive 'guillotine rupture' type leak creating layer of liquid. The evaporating liquid would create a fog from the cooling atmosphere, saturated with humidity (*)
  - a pressurised leak of gasoline from a rubber seal in a union on a 12'' fill line.

The lack of wind (*) limited the drift and thus the dissipation of the cloud of vapours.

- The calculation shows that the evaporation rate of the premium-grade gasoline enabling a 25,000 m³ cloud to be created in 20 minutes (between 0.8 and 5.5 kg/s) is too low to support the hypothesis of natural evaporation from a surface as large as the catchpit. This hypothesis is also not in keeping with the observations (formation of a fog, retaining catchpit totally wetted).

Union responsible for the leak

- *Valaurie accident* (Jan. 4, 1989 – No. 175) -

An agricultural implement equipped with three 0.90 m teeth perforated a 40 cm-diameter conduit buried 0.80 m below ground conveying gasoline at a pressure of 21 bar (max. service pressure: 75 bar). The resulting jet sprayed 15 m into the air with an immediate flow of 44 m³/h which caused a drifting aerosol cloud to form (50% of the LEL at 175 m from the leak, 10-20% at 1 km); 20 people were evacuated in a radius of 1 km. The water table was significantly contaminated over 2 ha: 400 mg/l at the leak, 660 m³ dispersed. 120 m³ of surpernatant was recovered, the rest of the pollution was eliminated by lowering of the water table and pumping until 12/25/89 with dilution to 80 times and release into the neighbouring river.

- On the other hand, the hypothesis of a faulty seal enables a flow rate of this magnitude to be obtained based on a hydrostatic leak under pressure (the height of the liquid had reached 9 m), considering that at least 10% of the jet is vaporised immediately. The high vapour pressure of this product (0.6 bar) makes this hypothesis plausible.

- Other accidents (particularly the perforation of the SPMR pipeline at Vallaurie (Drome), January 4, 1989) highlighted the capacity of premium-grade gasoline to form an aerosol fog from a turbulent jet. In these conditions, the risks presented by a cloud formed by premium-grade gasoline are comparable to those of a cloud of gas and flammable aerosols.

- At the time of the accident, the strength of the joints was guaranteed by their manufacturer to concentrations of aromatics up to 30%. At the time of the accident, the union at fault, commissioned 15 years ago, was subjected to lead-free premium-grade gasoline containing 55% aromatics.

- Despite the various hypotheses concerning the triggering and development of the accident, there remains doubt as to the exact origin of the leak and the diffusion of the hydrocarbon cloud.

ACTION TAKEN

- A prefectoral suspensory order was established October 30, 1991, as well as provisions to decontaminate the water table. The depot's reopening is contingent on the completion of a complete application for approval to operate. A detailed study of the accident and its causes was undertaken by an investigating bureau. A specialised laboratory conducted a study relative to the unseating of a seal similar to that fitting on the union.
- Two specialised companies conducted a soil pollution study and proposed treatment involving "soil venting", a vacuum extraction process.
- The tank farm resumed its activities November 2, 1993.

(*) Atmospheric conditions on the day of the accident: temperature 5 ℃, nearly no wind, high humidity (mist).

LESSONS LEARNED

- A better understanding of the content of aromatic components in lead-free premium-grade fuels with a high octane rating and the behaviour of seals is indispensable when designing and maintaining installations in which premium-grade gasoline is implemented.
- The training of personnel handling this type of fuel, concentrating essentially on the fire risk, must also focus on the risk of explosion and the safety measures to take should an aerosol cloud form. The behaviour of the tank farm employees and the drivers testify to a lack of experience with regard to this relatively unusual risk.
- The effects noted following this accident exceed, in both extent and severity, the consequences of reference scenarios habitually retained in danger studies dealing with hydrocarbon tank farms or for controlling urban development around these installations.
- Beyond simply respecting current regulations, fire fighting and rescue means must be dimensioned according to special local characteristics and emergency procedures must take into account the availability and performance characteristics of equipment in actual emergency conditions. In this respect, operators and emergency services must work together to ensure that contingency plans operate correctly in the event of an accident.
- The tank farm's fire defence plan indicated that the for a fire similar to that which occurred October 7, 1991, there should have been 5 l/m².min of foam concentrate applied, a water flow rate of 22,000 l/min. and the fire should have been extinguished in 20 min. The differences noted between this theoretical approach and reality bring to light certain elements:

  The plan was based on the fire spreading over 4,340 m², and not 6,560 m²,
  - of the 13 fire nozzles supplied, 3 were protecting peripheral tanks, the overall rate of water dedicated to extinguishing the fire was only 21,600 l/min,
  - a theoretical yield of 100% was retained for the surface distribution of the foam, although the yield is less in practice (mixture of foam concentrate, qualities, ageing…),
  - extinguishing a lead-free gasoline fire had never really been studied. Obviously, the reaction of this hydrocarbon was not expected faced with the habitual extinguishing methods and it required special foam concentrates that are habitually used for polar liquid fires.

In addition, the firemen had significant difficulty in finding the necessary equipment resources. The fact that the operator had to call on numerous external resources, not for reinforcement but for the initial assault, is not compatible with the basic requirements of emergency operations, for which time is a deciding factor.

- The relatively low cost of the intervention (*) explains the following points:
  - efficient operation owing to initiation of the internal contingency play and the fire brigade's cooperation in developing it. According to the internal contingency plan, 14 emergency response centres from the *département* were summoned as well as reinforcement from neighbouring *départements* (Vendée, Morbihan, Finistère, Maine-et-Loire and Ille-et-Vilaine),
  - material assistance provided by the region's major manufacturers, within the scope of a mutual assistance convention,
  - the implementation of all elements of a special intervention plan by the CODISC.
- The importance of considering the possible domino effects on neighbouring installations must also be stressed as numerous elements may have participated in aggravating the accident without assistance from the emergency services (notably, cooling of the LPG tank). It was also noted that the explosion, which projected metal fragments several hundreds of meters, had pierced a 15,000 m³ tank of fuel. A zone located below the fill level would have been it if the vehicles destroyed during the accident had not acted as a shield…

BIBLIOGRAPHY AND ADDITIONAL INFORMATION

- Inter-Ministry circular of July 6, 1990 relative to the fire fighting equipment in older flammable liquid storage facilities.
- Technical instructions and circular of November 9, 1989 relative to above-ground flammable liquid storage facilities.
- In addition, numerous de accident reports concerning hydrocarbon tanks are available at the address http://www.aria.ecologie.gouv.fr in the chapter entitled "Detailed historical accidents": explosion of a hydrocarbon tank at Lespinasse (31) in 2001 (NAF 51.5), explosion of a drifting cloud from a tank containing effluents charged with hydrocarbons in Italy in 1999 (NAF 51.5), diesel fuel leaks polluting a canal in Belgium in 2002 (NAF 23.2), a FFO leak in Gennevilliers (92) in 2001 (NAF 63.1).

(*) The cost was evaluated at 2 MF (300,000 €), including 1.15 MF of foam concentrate, the cost of the fire-tug, rental of a self-propelled crane and fees. It represents at least 0.5% of the value of the property exposed during the accident.