Fire in a hydrocarbon depot at the Édouard Herriot port

2 and 3 June 1987

Lyon [Rhône]

France

Explosion
Fire
Hydrocarbon depot
Additives
Hydrocarbons
Defective maintenance
Works
Pump
Victims
Material damage
Breathers or equivalent devices

THE FACILITIES INVOLVED

The Édouard Herriot port spanning over 150 hectares forms the northern part of a predominantly chemical and petroleum industrial sector of national importance extending to the south of Lyon. Several companies use the hydrocarbon depots representing a total storage capacity of 400 000 m^3 that is served by pipelines and waterways. The nearest residences were 750 m away along with a sports complex including a stadium with a capacity of 40,000 at 300 m. A public roadway circles the depot at the Édouard Herriot port and the A7 motorway was 2 km away.

The 43 000 m^3 depot in question was built in 1949 and at the time of the accident included:

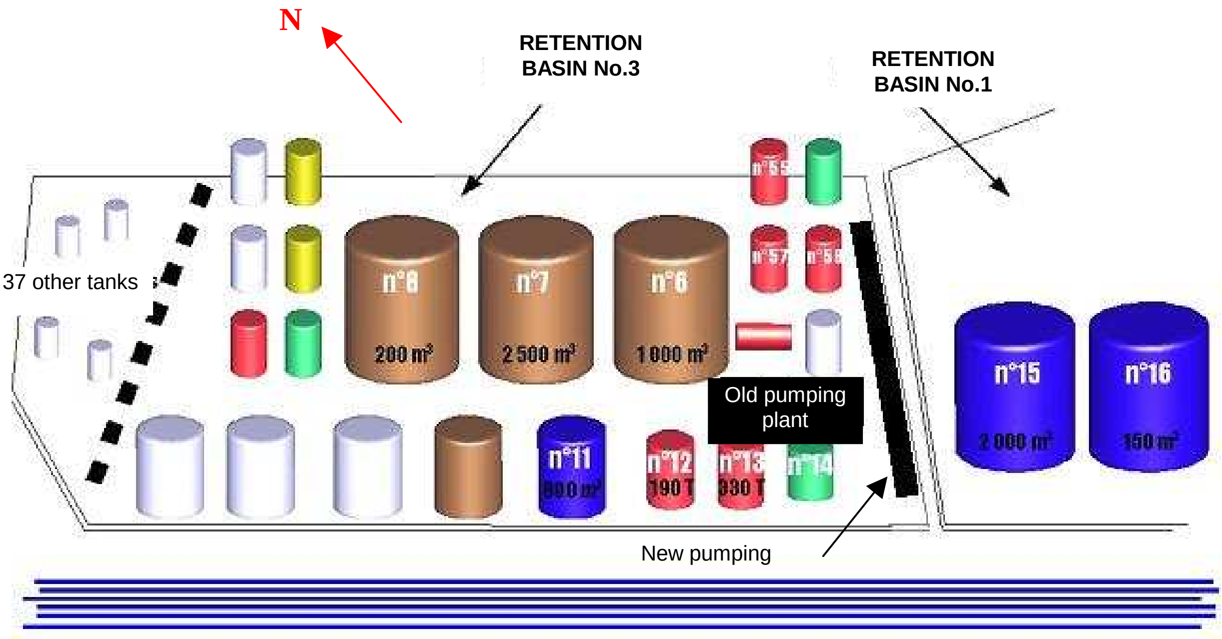
- ✓ 16 fuel tanks (flash point < 55℃) with a total nom inal capacity of 19,920 m^3.
- ✓ 6 diesel fuel and domestic fuel oil (55℃ < flash p oint < 100℃) with a total nominal capacity of 18,4 60 m^3.
- ✓ 54 lubricant tanks (category D: flash point > 100℃) with a nominal capacity of 4,232 m^3.

Other hydrocarbon or chemical depots were located less than 50 m from the boundaries of the site.

The depot operated under the prefectoral order dated 28 January 1948 that underwent several amendments. On 5 August 1985, the operator sought a temporary permit to manufacture fuel additives that was granted by the temporary prefectoral order dated March 1986 that was renewable every 6 months and expired on 12/03/87. During the accident on 2 June 1987, the fuel additive manufacturing facilities were thus no longer authorised to operate under the legislation governing classified facilities.

The accident started at the retention basin no. 3 that was as old as the site itself. A pumping plant and 58 tanks with an individual capacity ranging from 30 m^3 and 2 900 m^3 were installed on a 5 400 m² surface divided into 7 compartments. The total storage capacity at the time of the accident was 23 000 m^3 including 8,000 m^3 of fuel.

A part of the tanks of the retention basin and the pumping plant were being modified for a year to be temporarily used to manufacture fuel additives. At the time of the accident major operations were underway to permanently modify the tanks and design a new pumping plant even though the other tanks were normally operated. In the area in question, a dozen working stations were set up and prefabricated equipment stored. The 2.2 m high bund walls and containment dikes surrounding the retention basin no. 1 were disassembled locally for easier access to install equipment (cranes, generator sets, etc.). These operations were not included in the application for permit under review and were not declared prior to their completion.



Caption: **Oil lubricants** **Premium grade gasoline** **Non-degassed vacuum** **Additives**

Diesel fuel / domestic fuel oil

200 m³ / 190 T: volume / quantity present in the tank at the time of the accident

Figure 1 *- Diagram of the main facilities*

THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

The accident:

- Around 1.15 pm: a team of technicians moved an electric cable connecting a generator to the welding stations inside the retention basin. An additive was released in form of a spray at that moment in the premises of the old pumping plant near the tank 14 in the retention basin 3. After a few seconds, a flash was produced.
- About a minute later, a violent explosion felt several kilometres was produced. Tank no. 14 collapsed on tank 13. A fire broke out in the sector of the pumping plant trapping some technicians near the eastern border of the retention basin. The depot's safety team promptly activated the sprinkler system.
- Around 1.25 pm, a chain of explosions occurred in the southern sector of the retention basin 3. The welded tanks no. 12, 55, 57 and 58 were projected in the air and then crashed on the ground. Tank 12 was vertically projected as high as 200 m in the air before it landed on a neighbouring dock 60 m away. The emergency resources set up at the base station were partly destroyed. The staff fell back. The accident rapidly spread to 1/3 of the retention basin. A thick cloud of smoke masked the storage areas. Five other tanks exploded and were projected inside the depot causing the fire to spread and making it impossible for the external emergency resources that promptly arrived to intervene.
- At 2.30 pm: Faced with the spreading fire, the Rhône prefecture triggered the PPI (external emergency plan).
- Until 5.00 pm, the fire continued to spread to the entire retention basin even though the waters in the facilities were cooled.

Figure 2 – Fire in the retention basin No. 3

- Around 5.30 pm: The water was cooled for 4 hours. The fire had nearly spread to a surface of 4,000 m² and all necessary fire-fighting equipment had been gathered. The fire fighters then used foam to fight the flames but the attack was slowed down by the several entangled and overlapping equipment.
- Around 6.30 pm: While the fire was subsiding, the 2 900 m³ welded tank no. 6 that was filled to 1/3 of its capacity with diesel fuel emitted a strident hissing sound.
- At 6.32 pm (according to the emergency team on site): When the rescue workers took shelter behind an adjacent building, tank 6 containing 1 000 m³ of gas fuel literally exploded forming a 300 m high fireball with a 200 m diameter for about 15 seconds. It collapsed partly outside the retention basin.
- During the night: The fire spread from tank 3 to tank 1 whose containment dikes were partly disassembled as well. Two floating roof tanks no. 15 and 16 containing premium grade gasoline caught fire. The neighbouring dock was isolated using an oil boom. The sewage network was clogged and the adjacent chemical depot protected by water curtains. Other oil companies, manufacturers of foam compound and the emergency services of neighbouring establishments participated to help collect 400 m³ of foam compound.
- From 6.30 am the following day: Several types of fire fighting equipment were used in the final attack on the blaze with foam. Two flares escaped from tank 7 without any damage to its shell. However, the emergency workers feared an explosion similar to that of tank 6. The blaze on tank 15 and 16 was put out first. A sharp decrease in the fire was finally observed around 11.00 am.
- At 2.00 pm: the fire was brought under control in the entire site and the cooling of the tanks continued.
- At 7.45 pm: the PPI (external emergency plan) was lifted and the operator took control of the rescue operations within the framework of the POI (internal emergency plan).

Figure 3 – Sight of the fire ball developed above the retention basin No. 3

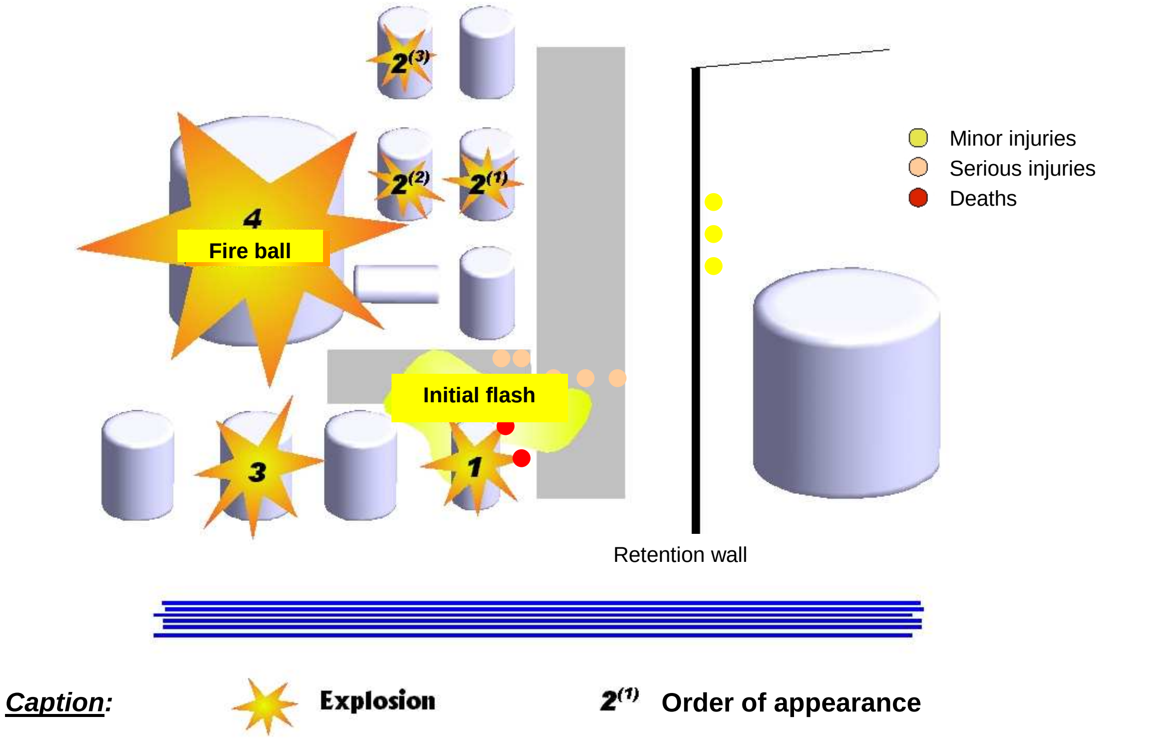


Figure 4 - Site and order of appearance of various explosions during the accident – Localisation of victims

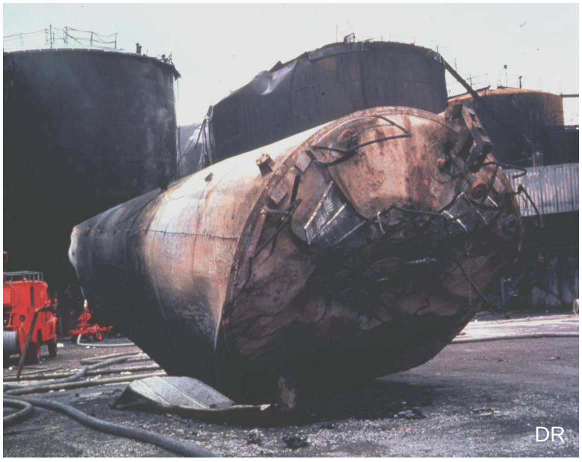
Fire fighters, police and medical emergency team were quick to act (4 fire brigades made available after 8 minutes, safety perimeter set up by 4 police squads after 10 min and administration of medical care to victims by the SAMU (French EMS) after 15 min).

Over 200 policemen and some 200 fire fighters from several departments were involved for over 24 h. More than 200 m^3 of foam compound supplied by oil companies, manufacturers and fire-fighters from the neighbouring departments were used including 72 m^3 for the first round of attack and 40 m^3 for the final round. The emergency resources were considerably stepped-up for the final and determining round of attack: 15 foam deluge sets, 2 very high power vehicles (6 000 l/min).

Figure 5 – Final intervention with foam in morning of 3 June

The consequences of the accident:

The 2 technicians present near tank no. 14 during the initial flash and then trapped by the fire died. The flash also burnt 8 other technicians including 5 seriously. Three of the technicians were on the framework of the new pumping plant under construction at heights, while the two others were beside the control panel of the pumping plant in service. The technicians in retention basin 1, protected by the retention wall only sustained mild injuries (see figure 4). Six fire fighters were reported to have sustained mild injuries during the explosion of tank 6.

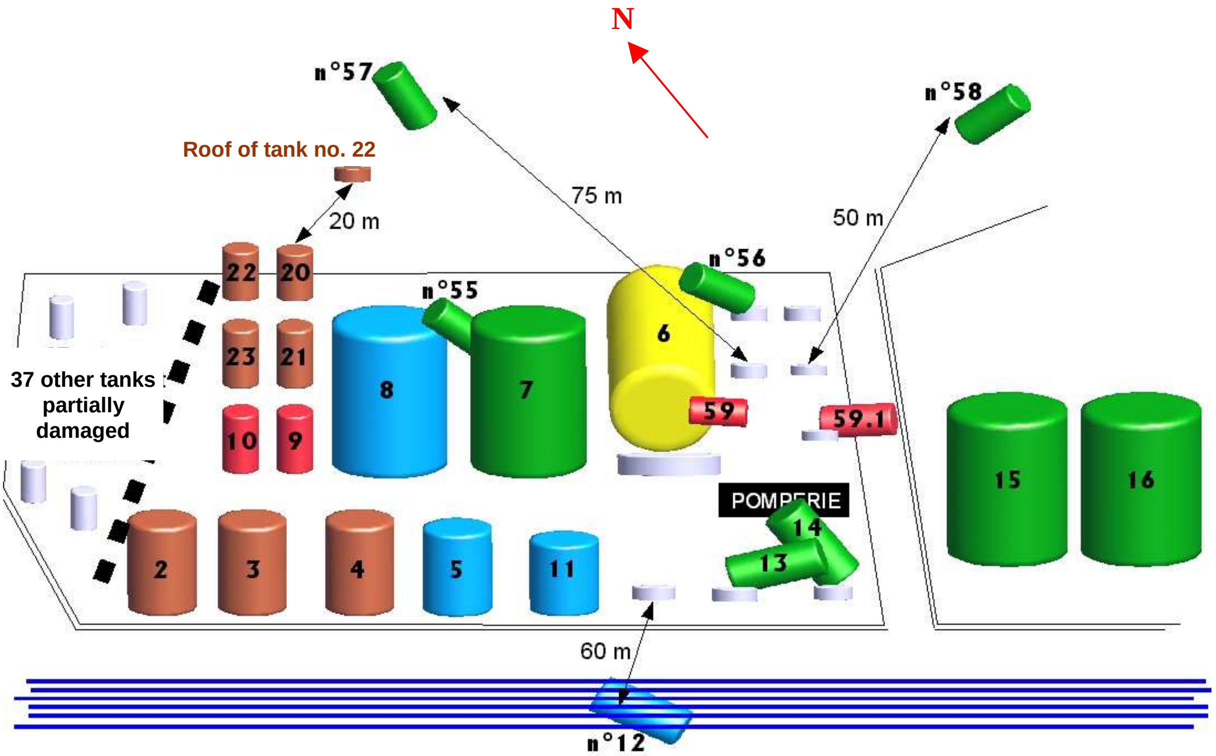


Figures 6a & 6b – Tank « blown » by the 'explosion (above)
And tanks damaged by the fire (right)

The accident resulted in significant material damage. Almost all tanks contained in the retention basins 1 and 3 were either destroyed (tanks no. 6, 12, 14, 55, 56, 57, 58, 59, 59.1, 20 and 22) or suffered considerable damage and could not be re-commissioned. In all, 14 tanks and around 4 km of pipelines were impacted. The loading stations, offices, packaging workshops and the neighbouring construction site equipment were also destroyed.

By comparing the fuel stocks before and after the fire, it can be estimated that the following quantities were either consumed or spilt:

- 1 900 t of domestic fuel and diesel fuel (2 200m^3)
- 1 200 t of petrol and premium grade gasoline (1 500 m^3)
- 600 t of fuel additives



Caption: **Shell burnt** **Roof and shell deformed and not ripped** **State unprecised**
Shell deformed, roof ripped/ damaged **Shell totally ripped**

Figure 7 – Material damage on facilities and typical falling distances

Figure 8 - Cloud of smoke above Lyon

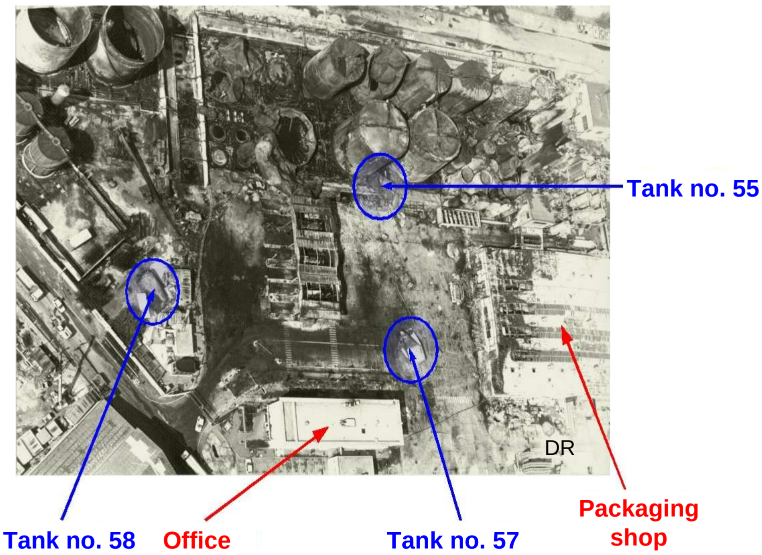


Figure 9 – Aerial view of facility after the accident

A part of the water used on fire and the hydrocarbons spilled inside and outside the retention basins and seeped into the permeable soil. Monitoring with piezometers that was already in place was stepped-up. Four new wells were dug in the vicinity of the retention basin in question. The ground water table monitoring that was in place until 2001 in the accident site and in the entire depot detected no special incident of pollution further to this accident. The urban sewage network was prevented from being polluted as the sewage system of the oil sector was isolated right from the start of the accident through oil booms installed on the dock and the Rhône River. The 6 000 m³ of polluted water collected in the oil booms was disposed. The polluted water and hydrocarbons remaining in the tanks and drains (around 10,000 m^3) were pumped out and transported by flotation barges and wagons to the south east refineries for treatment in the internal stations.

Weather conditions (light wind in the eastern sector at the start of the fire followed by a long calm period during the night) helped the smoke cloud rise vertically above the site. The atmospheric emissions mainly included dust in the form of unburnt products, sulphur dioxide, lead compounds, and vapours and breakdown products of basic chemicals used in manufacturing additives. Despite the huge quantities of dust released into the atmosphere during the accident, the concentrations measured in the environment do not show a marked variation in the concentration of pollutants in the Lyon region during the accident. It is possible that a part of the pollutants were transported beyond the surveillance perimeter of the region.

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 the 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.

The "dangerous Materials Released" Q1 parameter was rated at 4 due to the emission of 3 700 tonnes of products classified by SEVESO as "oil derivatives" (1 900 tonnes of domestic fuel and diesel oil + 1 200 tonnes of petrol and premium grade gasoline + 600 tonnes of additives 14.8% of the 25 000 tonne upper threshold of the Seveso II directive).

The human and social consequences index was rated at 3 on account of the 2 victims (H3 parameter).

Since environmental consequences of the accident could not be formally assessed, the corresponding index was not rated.

At least a level 4 rating was given to the "economic consequences" index as internal material damage was assessed at 130 million F in 1987 (€15 parameter).

THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THE ACCIDENT

The precise origin of the accident could not be traced back. After a 7-year enquiry, legal experts retained the possibility of insufficient maintenance of the barrelling pump that was left to operate at a zero bleed-off rate of flow during the lunch break. This caused the equipment and a product involved in the manufacture of the additive to overheat. The exothermic breakdown of the product may have created an opening through which the flammable liquid may have escaped. The flammable stream of liquid could have been ignited either by auto-inflammation or static electricity created by the passage of the liquid through the hole. The legal expertise failed to provide any evidence of a torch blow-pipe or grinder used in the initial accident area. Moreover, the 1st explosion was preceded by the noise of a pump that started and by a rattling noise, a sign of product instability (static or dynamic). The other theories relating to this thermal phenomenon in the tank's insulation could not be discarded: fire in the insulation of a pipe that may have been triggered by fly ash from works involving hot spots carried out a few hours back or the phenomenon of "punking" calling in question the slow phenomena of catalysis oxidation and finally auto-inflammation of a product impregnating the rock wool making up the insulation.

Chain explosion of additive tanks:

The first question raised was on the speed and impact at which the accident spread. Oil depot fires of accidental origin usually spread in a less abrupt fashion and with a low impact. The accident was triggered in an additive manufacturing zone and engulfed the neighbouring small tanks that greatly contributed to the accident due to chain explosions. Several factors may have contributed:

- The additive involved was a "combustion enhancer" aimed at optimising motor performance. The analysis carried out as part of the legal enquiry revealed its instability at temperatures ranging from 130 to 160℃ that are quickly attained when a tank in the retention basin catches fire. These products rapidly broke down to form thermal decomposition gas.
- Tanks with limited capacity (see figure 1) are potentially a greater hazard in the event of retention basin fires. Their quick heating may be aggravated by a low storage factor. The internal vapour pressure increases rapidly causing the product to evaporate and the gas inside or outside the tank to ignite causing the tank to rupture under pressure. Post-accident studies carried out by the operator revealed that when the metal sheet comprising the walls of the tank is exposed to fire, a temperature of 500℃ can be attained in 2 min b y the portion below the liquid level.
- The depot was operational at the time of the fire: the valves at the base of the tanks that were manual were opened and thus leading the fiery pool to be fuelled by pipelines destroyed by thermal flows (see photo 6b). Moreover, the loss of products from the foot of the tank favoured the flow of oxygen to the gaseous atmosphere above the tanks creating conditions conducive for explosion.

Two phenomena may have caused the additive tanks to explode:

- Internal overpressure generated by the massive formation of distillation gases and/or decomposition gases that did not escape through the valves.
- Auto inflammation and explosion of the gaseous atmosphere. This theory is supported by the operator in a technical report on the rupture of the shell / bottom of the additive tank no. 12. The study also explains that in a tanks filled to around 1/3rd its volume as it was the case for tank no. 12, pressure developed during the explosion (about 1.5 bar) provided the tank with a rising velocity of 44 m/s (i.e. about 160 km/h) through piston effect when the contents flowed out of the tank.

Additive tanks were designed to be frangible but generally ruptured at the junction of the shell and bottom. The domino effects worsened the accident further to the initial explosions.

More specifically tank no. 14, the first to have exploded and where the initial flash occurred, was empty, not degassed and used to store additives. It was equipped with a steam heating system to maintain the product between 20 and 30 ℃.

Tank 12 that was projected 200 m upwards was previously used to store hydrocarbons whose flash point ranged between 55 ℃ and 100 ℃. But since March 1986 it w as used in the manufacture of additives. It included a "jet mixing" system to allow mixing a full tank and a vapour heating system. At the time of the accident, the additive in the tank, filled to one-thirds of its capacity, was manufactured 2 days before. The additive was being pumped to the barrelling station. The tank was filled to one-thirds of its capacity at the time of the accident.

Moreover, the foam liquid used by the fire fighters was adapted to hydrocarbon fires but not to polar compounds also present in the retention basins. These compounds destroyed the foam layer built by the emergency services.

Special case of diesel fuel tank no. 6:

Contrary to what was assumed for a long time, the fire ball of the non-insulated tank no. 6 with a welded design was not a “boil over” phenomenon. In fact, tests performed by an expert revealed that a “standard boil over”[1] was not possible in a diesel fuel tank and the phenomenon of “thin-layer boil over”[1] involving this fuel would have had a lesser impact and a clearly smaller fire ball.

Strident hissing sounds were heard from tank no. 6 a few seconds before the roof reputed to be frangible, and the shell ruptured releasing the fire ball. Witnesses reported a 20 m flare on tank no. 7 containing 2500 m^3 of diesel fuel located adjacent to tank 6 and having the same dimensions. At the time of the incident, the 2,900 m^3 tank no. 6 filled to one-thirds of its capacity, i.e. 1 000 m^3 of product thus contained 2,000 m^3 of pressurised gas. This explosion could consequently have resulted from the pressurisation of the tank or a similar phenomenon assuming that the valves set at 175 mbar failed to evacuate the excess pressure resulting from the vaporisation of the product. The expansion and ignition of the gaseous atmosphere under pressure and the dispersion of the overheated liquid (thermodynamic flash and carry-over of droplets) triggered by decompression subsequent to the rupture of the tank may have contributed to the formation of such a fire ball.

During the fire-fighting operations with foam compound on the 3 June, the firemen feared the explosion of tank no. 7 in the same way. Since it was insulated, the rise in temperature was gradual and was able to resist the intense heat of the fire for 22 hours.

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[1] « *Boil over and other phenomena generating fire balls concerning flammable liquid depot storage tanks* », June 2007; appended to Circular DPPR/SEI2/AL-07-0257 of 23 July 2007 on the assessment of risks and impact distances around flammable liquid and liquefied gas depots.

ACTIONS TAKEN

Further to the accident, securing the depot required all tanks and facilities containing flammable products to be emptied and degassed. These operations started on 4 June after the temperature of the tanks and stored products returned to normal.

The Inspection authorities for Classified Facilities recommended the Prefect (departmental head) to issue an order requiring the operator to take appropriate measures to not dispose off water polluted with hydrocarbons into the natural environment and have the water table constantly monitored by a specialised company. The re-commissioning of the facility was subject to a new permit. The operator was fined and certificates of offence were issued against him for operating an inflammable liquid depot without permit. The judicial investigation for the disaster lasted 7 years (from June 1987 to May end 1994). The site was finally never re-commissioned and the facilities were dismantled in 1995. Various appeals and procedures (administrative and criminal) were instituted between 1994 and 2000. The last sentence on appeal dated 21 December 2000 confirmed the liability of the operator for the death of 2 people and ordered the payment of 1.4 MF to the civil parties. The Director of the depot was personally given a 15 month suspended sentence and fined 30,000 F.

Further to this accident, the local players including operators, administrations and regional authorities held a series of discussions on both the safety of oil depots and the vocation of the Édouard Herriot port. This resulted in a protocol agreement on 24 March 1997 that led to the shutdown of 4 out of the 8 facilities near the sports complex. The agreement resulted in significant modifications in the entire Édouard Herriot port:

- Freeing-up of 10 hectares of land
- Separation of oil depots from public facilities
- Optimisation of tanker truck traffic
- Destruction of around 40 tanks
- Construction of 6 hydrocarbon tanks as well as new loading stations.

LESSONS LEARNT

Further to this major accident, a multidisciplinary national working group was set up bringing together representatives from inspection departments, administrations, oil depot operators, and trade unions. The efforts of the group resulted in the publication of **technical report dated 9 November 1989** on existing flammable liquid aerial depots that especially includes:

- ✓ Urban development around industrial sites
- ✓ Surface and underground water protection measures
- ✓ Preparatory fire-fighting measures
- ✓ Depot layout regulations
- ✓ Depot management regulations

This accident especially illustrates the need to:

- ✓ Carry out a preliminary risk analysis before starting any works session and take the adequate measures when a safety component is destroyed (e.g. emptying tanks or constructing temporary bunds when the water tightness of the retention basin is no longer guaranteed).
- ✓ Assess risks and possible domino effects related to manufacturing, and especially mixing additives within depots.
- ✓ Install breathers of appropriate size or any other device that releases overpressure in tanks in the event of fire and maintains a sufficiently low pressure to minimise the risk of rupture of the capacity and the possible formation of a fire ball when the accumulated pressure drops.
- ✓ Install automatic remote controlled devices to shut the valves on the foot of tanks in the event of fires such as flap valves[2] to avoid feeding the blaze in the retention basin in the event of rupture of pipelines during a fire.
- ✓ Promote the use of polyvalent foam compounds or store products requiring different foam compounds in separate retention basins.

[2] Flap valve maintained in open position by a compressed switch that melts when exposed to heat causing the flap to shut under its own weight. A lever is used to reset the valve.

Other major oil depot fires listed in the ARIA database:

- ARIA 2914: Explosion followed by fire in a hydrocarbon depot in Saint Herblain on 7 October 1991.
- ARIA 3396: Fire in a hydrocarbon depot in Saint Ouen on 14 June 1991.
- ARIA 6007: Boil over of a crude oil tank in Milford Haven (United Kingdom) on 30 August 1983.
- ARIA 31312: Explosions followed by a fire in an oil depot in Buncefield (United Kingdom) on 11 December 2005.

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