BLEVE in an LPG storage
Facility at a rafinery
January 4, 1966
Feyzin (Rhône)
France

BLEVE
Fire
Domino effects
Refinery
LPG
Purge valve
Instructions
Organisation of emergency
Victims
Material damages
Projectiles

THE INSTALLATIONS IN QUESTION

The site:

The Feyzin refinery, located south of Lyon, was commissioned in July 1964 and designed to process 1.7 million tons of petroleum per year. In early 1966, the refinery was fitted with a pressurised liquid petroleum gas (LPG) storage facility having a total capacity of 13,100 m3. The site received authorisation by prefectoral order dated April 20th, 1962, modified by orders of May 4, 1962, August 4, 1964 and July 30, 1965.

The LPG storage area is located in the refinery's zone B, south of the production units. In addition to the LPG storage facility, which includes 10 tanks, 8 spheres and 2 cylinders (see figure 1 below), zone B also includes storage containers for furnace fuel-oil, gasoline and premium. Zone C is located on the other side of the motorway, south-east of zone B and corresponds to the tanker loading zone.

The nearest part of the LPG storage facility is located 22.50 m from the A7 motorway trench, which passes 1.50 m below the ground level. The butane spheres are spaced 11 m apart and the propane vessels at a distance of 11.8 m. The LPG spheres are filled by 2 corresponding horizontal tanks (or "jet tanks").

All the tanks underwent hydraulic testing in 1964.

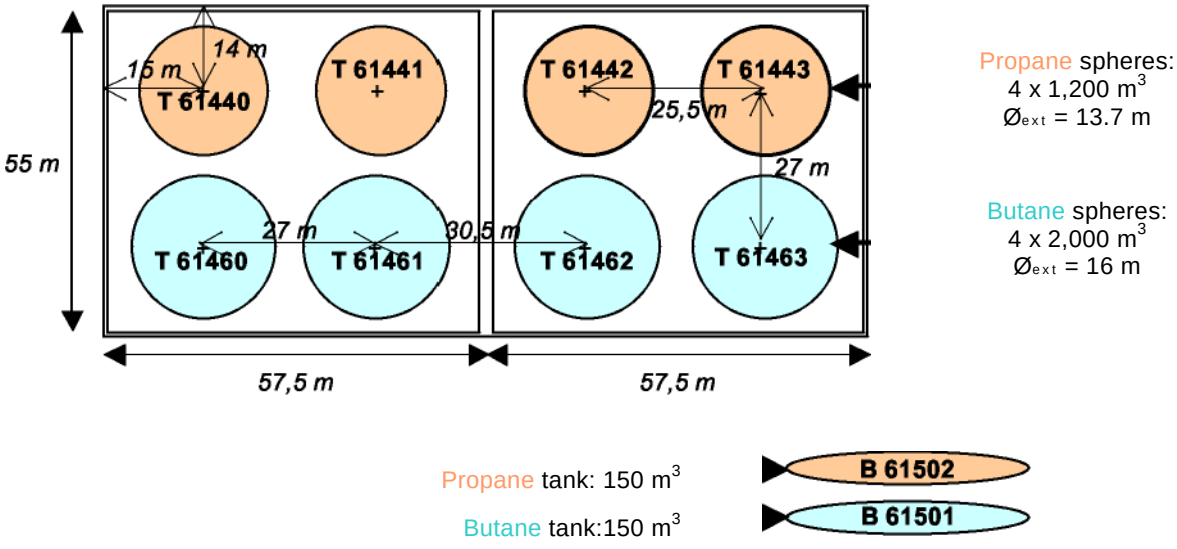


Figure 1 – Representation of the LPG storage zone

Tanks:

The following table summarises the characteristics of the LPG storage tanks:

Tank	Steel grade	Volume	Dimensions	Pressures	Sheet thickness	Empty weight
Propane spheres (440, 441, 442, 443)	BH 36 KT (carbon steel)	Total volume: 1,218 m³ Max. useful volume: 1,090 m³	Diameter: 13.27 m	MSP: 18.7 bar Test pressure: 28.05	42 to 43 mm	220 t
Butane spheres (460, 461.462, 463)	BH 36 K (carbon steel)	Total volume: 2,038 m³ Max. useful volume: 1,816 m³	Diameters: 15.74 m	MSP: 7.97 bar Test pressure: 11.95 bar	24.5 to 25.4 mm	186 t
Propane/butane tanks	BH 36 KT	161 m³	Diameter: 3.040 m Length: 20.800 m	MSP: Test pressure: 28.05 bar	Bottom: 11 mm Shell: 20 mm	

Table 1 – Tank characteristics

The purge valves

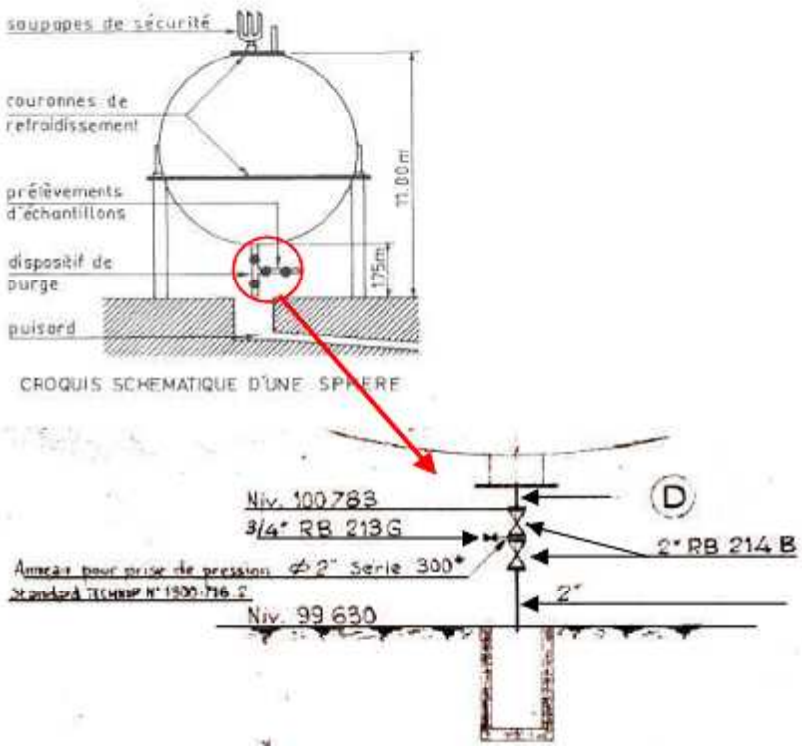


Figure 2 – Schematic representation of the purge device

The spheres (4 per catchpit) are equipped with:

- on the lower section, a purge designed to periodically drain the manufacturing residues that have accumulated after decantation. This device consists of a ¾" sampling tap between two 2" purge valves, located approximately 70 cm from a cement sump through which the purge liquid flows into the refinery's polluted water network.

- three 3/4'' dia. lateral sampling taps

- branch connections and instrumentation: 3 temperature taps, a level indicator and a pressure gauge.

At the bottom, the purge valves are lubricated ¼-turn tapered plug valve manufactured by Audco Rockwell. These valves are operated manually by means of a square drive valve wrench. The purge fittings measure 2'' in diameter (50 mm), and that of the sampling tap is ¾'', approximately 20 mm.

The 2 purge valves are located about 260 mm apart. The pipes located between the 2 valves are equipped with a rudimentary steam heating device and lagging.

Base of the spheres:

The spheres are supported by 10 tubular posts, anchored in foundation blocks by 2 expansion bolts:

- O.D. 610 mm and 6.5 mm thick for the propane spheres,

- O.D. 710 mm and 7.5 mm thick for the butane spheres.

Tank protective devices:

✓ The spheres are equipped with 2 valves (Sapag 1910 6'' to 8'' type for the butane spheres, and Sapag 1910 p 4'' to 6'' type for the propane spheres): only one is in operation at a time, while a 3-way "double" valve is mounted upstream. The are compliant with American standard API 520 (September 1960).

As far as the propane spheres are concerned, the valves can discharge 71 t/h at 50°C.

✓ For cooling purposes, the spheres are equipped with the following cooling apparatus:

- 2 spraying rings, on the upper section, and one at the mid position

- a spraying system for the lower section.

The propane spheres are thus equipped with a total of 18 sprayers delivering 1.8 m³/min./sphere (or roughly 3 l/m²/min.) and the butane spheres have 22 sprayers delivering 2.2 m³/min./sphère (or roughly 2.7 l/m²/min.), which represents 960 m³/h for all the spheres.

✓ The cylindrical tanks are cooled by spray booms.

Fire protection water network:

The network consists of a 12,000 m3 pond, 2 motor-driven pumps (one electric and one diesel-powered) delivering 400 m³/h at 14 bar into a grid network made up of 8'', 10'' and 12'' pipes. Zone B, which includes the LPG and flammable liquid storage facilities, is equipped with 20 fire hydrants and 10 fire plugs.

A branch connection from the network also supplies an LPG storage facility located in a neighbouring establishment (beyond zone C) and with also includes 2 LPG spheres.

The site's fire brigade was made up of 9 firemen and was assisted by 44 auxiliary firemen.

THE ACCIDENT, ITS BEHAVIOUR, ITS EFFECTS AND CONSEQUENCES

The accident:

On the morning of January 4, 1966, a series of explosions and fires occurred in the refinery's LPG storage zone.

At 5 am, on the morning of January 4, 1966, the parameters of the spheres were as follows:

The consequences:

Storage sphere designation	Condition	Height of hydrocarbons	Volume at 15°C	Weight	Temperature
T 61440	Closed (stationary)	3.714 m	234 m³	118 T	12 °C
T 61441	Open (drainage)	2.853 m	147 m³	74 T	7 °C
T 61442	**Closed (stationary)**	**8.465 m**	**895 m³**	**452 T**	**11 °C**
T 61443	**Open (filling)**	**7.176 m**	**693 m³**	**348 T**	**10 °C**
T 61460	Closed (stationary)	10.960 m	1,596 m³	918 T	16 °C
T 61461	Open (drainage)	5.531 m	584 m³	337 T	10 °C
T 61462	Open (filling)	7.920 m	1,053 m³	605 T	4 °C
T 61463	Closed (stationary)	12.143 m	1,803 m³	1,036 T	11 °C

Table 2 – LPG tank capacities

Chronology:

On January 4th, sphere T 61-443 (referred to as No. 443) contained a gas having an excessive ethane content (12%): also, high-purity propane was also added. At the time of the accident, the sphere was being filled by the site's units. Analyses are required to monitor changes in the product and, consequently, on Jan. 03, a request to take a product sample was issued. A laboratory technician was in charge of the operation. A purge is required before conducting the operation :

- *Before 06.40 am:* While it was still night time and with not much ambient lighting, the laboratory technician entered the area to take a sample from the sphere. In order to perform the initial purge operation, he asked for assistance from a security agent and a helper who would be performing the operation.

- the lower sampling tap was normally used for sampling operations, as the 3 side sampling taps were often frozen and difficult to access.

- *06.40 am:* The helper claims that he opened the lower valve half-way, then opened the upper valve even further: The sodium-containing water poured out and a small amount of gas was released. He then closed the upper valve. Before finishing the purge, he opened the valve again: a bit of liquid flowed out, then stopped. He opened the upper valve wide open.

- After a few seconds, the noise of an explosion was heard and the propane sudden blew out, ricocheting out of the sump, splashing the operator in the face and arm making him jump back. With his safety goggles ripped off, he attempted to find his way back through the cloud to close the upper valve but the mobile valve wrench, the nut of which was not secured, had slipped out of the stem square (it remained suspend, hooked onto a grease fitting). He was unable to fit it back on the valve which had already become frozen by the release of gas. Forgetting about the lower valve, the 2 agents gave up, retreated and sounded the internal alarm.

- *06.40 to 06.50 am:* for 10 minutes, the establishment's security crew also tried, unsuccessfully, to stop the leak. Both valves had frozen. Due to there practically being no wind at all and the very low temperature, the atmospheric conditions were helpful in diffusing the gas cloud. According to witnesses, the 1 to 1.5 m-thick propane cloud left the establishment and expanded by gravity onto the A7 motorway, along an open right angle toward the CD4.

- *06.50 am:* The guardhouse was informed and the employees attempted to stop traffic on the motorway and on the CD4.

- *06.50 to 07.05:* The helper that had performed the purge operation stopped the motors of the pumping station connected to the sphere. At 6.55 am, the guard station informed the customs officials of zone C: It took a newly-hired employee 10 minutes to contact the *gendarmerie* by telephone and request assistance. The call was placed around 7.05 am. Beforehand, a truck was able to pass through the gas cloud without it igniting. A dozen or so individuals parked along the CD4. The first emergency vehicles from the refinery began to arrive.

- *7.15 am:* A car enters the cloud. It drives along a road leading to Departmental Road 4 (CD 4), running parallel to the motorway, despite signals from one of the refinery's guards to stop. The vehicle stops approximately 160 m to the east of sphere 443. The cloud ignites against a hot point on the vehicle and the flame moves quickly by successive leaps toward the refinery. A minute later, the liquefied propane leak ignites at the source resulting in a violent torch.

- *7.15 am:* At that moment, the emergency services began to arrive in successive waves. The refinery's fire fighters attempted unsuccessfully to stop the leak. It should be noted that the spraying rings of the 2 spheres in the neighbouring LPG storage facility were activated, supplied by a branch connection from the refinery's fire fighting network. The rescue personnel use powder-type extinguishers and a powder truck (1,500 kg capacity) from the site. Various means are implemented: foam monitor, water canons 442, 443, 463...

- 7.20 am: The site's siren is triggered. The external firemen are alerted by a nearby resident and by the refinery guards (7.19 am). The fixed spraying systems on the 7 other spheres were started. Note that the site's 2 motor-driven pumps were not able to operate in parallel (flow rate limited to 400 m^3/h when mobile means are not taken into account).

Figure 2 - Sphere T 61443 on fire
Photo : le Progrès

- Starting at 7.30 am: Fire fighters from Lyon arrived around 7.30 am, nearly 50 minutes after the leak began. Water began to become scare and pumping operations in the Rhône were set up to assist the mobile means. The flow of butane and propane was diverted at the site.

- 7.45 am: The safety valve on sphere 443 opens due to the internal pressure of the LPG: upon release, the gas immediately vaporises and ignites, resulting in a 10 m-high torch. At that moment, the firemen stop spraying the sphere and essentially concentrate on cooling down the neighbouring spheres. The valve's opening is regarded as positive as it will allow the situation to be controlled within 2 or 3 hours, once the gas is consumed. At 8.05 am, one of the rescue teams chooses to secure the nozzles and withdraw the firemen.

- Around 8.15 am: The rescue services set up a high-power oil-fire type rescue vehicle is set up. However, due to a operating mistake, the unit becomes bogged down and remains blocked for 15 to 20 minutes. Following the arrival of fire fighters from VIENNE and reinforcements from neighbouring companies, 158 rescue personnel were present in a radius of 100 to 120 m around the storage tanks; 15 nozzles were in operation; at that time, the flames were 40 m high above sphere 443 which was not being cooled (it appears as though the sphere could not be cooled as the valve controlling the spray system quickly became inaccessible due to the intense heat).

- At around 8.30 am, equipment is installed to draw water from the canal but the operation is slowed down by the need to cut down the site's fencing (cutters, and then a mechanical digger). Owing to the lack of water and low system pressure, the rescue teams attempted to get closer to the spheres. According to witnesses, the intense heat prevented them from getting closer than 40 m.

- Around 8.45 am: Sphere 443 explodes. A fireball forms in just a few seconds and reaches nearly 250 m in diameter, reaching nearly 400 m in height.

- *At 8.55 am:* The emergency shutdown of the units is ordered. Zone B is evacuated: All of the personnel who had survived the explosion fall back.

- *At 9.30 am:* (approximate, as reports vary between 9.10, 9.30 and 9.40 am) The neighbouring sphere T 61442 exploded. No one was injured.

- *From 9.40 to 10.30 am:* The 3 adjacent butane spheres T 61461, T 61462 and T 61463, are subjected to intense thermal radiation or hit by fragments; they each open up without exploding (9.40, 9.50, 10.30).

- *At 10.10 am:* The "ORSEC" rescue plan is initiated.

- The fire caused by the first explosion rapidly spread to the 2 horizontal LPG tanks, B 61501 and B 61502, causing the 4 neighbouring jet fuel tanks to catch fire (containing nearly 2,000 m^3 of petroleum oil) and an adjacent tank of premium-grade gasoline.

Figure 4 – Illustration of butane sphere 462 on fire

The fire fighting efforts, extended throughout the entire LPG storage zone, and continued for more than 24 hours. A significant number of reinforcements were sent to the site. In the evening of January 5th, the alert was lifted even though a few fires remained active, fuelled by hydrocarbon leaks.

The consequences:

The accident resulted in 18 deaths (7 firemen from Lyon; 4 firemen from Vienne; 2 refinery employees; 3 employees from a subcontracting company; 1 employee from a neighbouring company who came to help; the driver of the car who drove into the cloud died 4 days after the accident) and 84 injured, 49 of whom were hospitalised.

The accident also resulted in extensive property damage both inside and outside the site. Outside the establishment, 1,475 homes and other constructions were effected by the explosions.

The fire destroyed or damaged the LPG and neighbouring liquid hydrocarbon storage facility, including 11 tanks (5 spheres, 2 horizontal tanks and 4 floating roof tanks). Product losses were calculated at 1,012 tons of propane (i.e. approximately 2,000 m^3), 2,027 tons of butane (i.e. nearly 4,000 m^3) and practically 2,000 m^3 of jet fuel, the equivalent of 1,500 tons of petroleum products. The pump station (located between the horizontal LPG tanks and the jet fuel tanks) and 6 fire trucks also were destroyed in the fire.

Figure 5 - General condition of the LPG spheres after the accident

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.

Level 6 is attributed to the "dangerous materials released" index due to the quantity of butane and propane (2,000 tonnes and 1,000 tonnes respectively) and liquid hydrocarbons (1,500 tonnes approximately) released during the various phases of the accident (Q1 parameter).

The level 5 for the human consequences is due to the number of external rescue personnel who died in the accident. Level 6 corresponds to the significant quantity of material involved in the event, either directly or indirectly: 880 t of propane, and 2,000 t of butane in particular.

There is no statistical information available to rate the economic consequences index, which none the less is very high.

Thermal effects and blast effect at the site:

Among the 158 people present at the site at the time of the accident, 42 were unable to return to work for a period exceeding 3 months. The totally unexpected blast and the intense heat radiation caused by the BLEVE (Boiling Liquid Expanding Vapour Explosion) from the first sphere decimated the rescue personnel. Everyone within 50 m of the sphere were killed, except for 2 firemen; those within a radius of 150 m were seriously burned. The injuries sustained by individuals located at further distances were generally much less serious.

At the site of the explosions, a crater measuring 35 m long, 15 m wide and 2 m deep was left, notably underneath sphere 442.

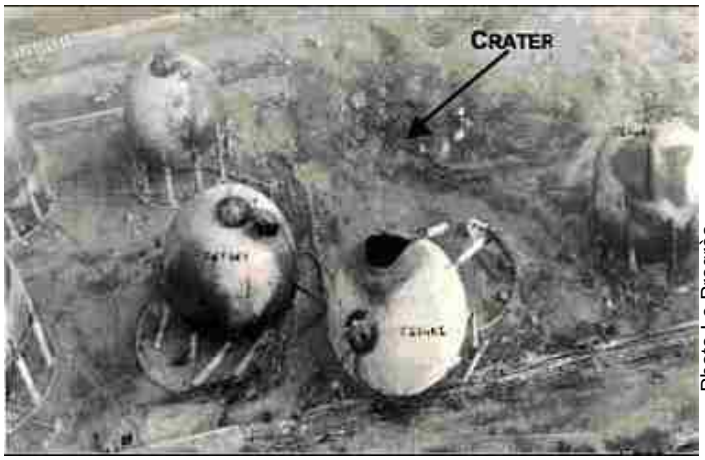


Photo Le Progrès

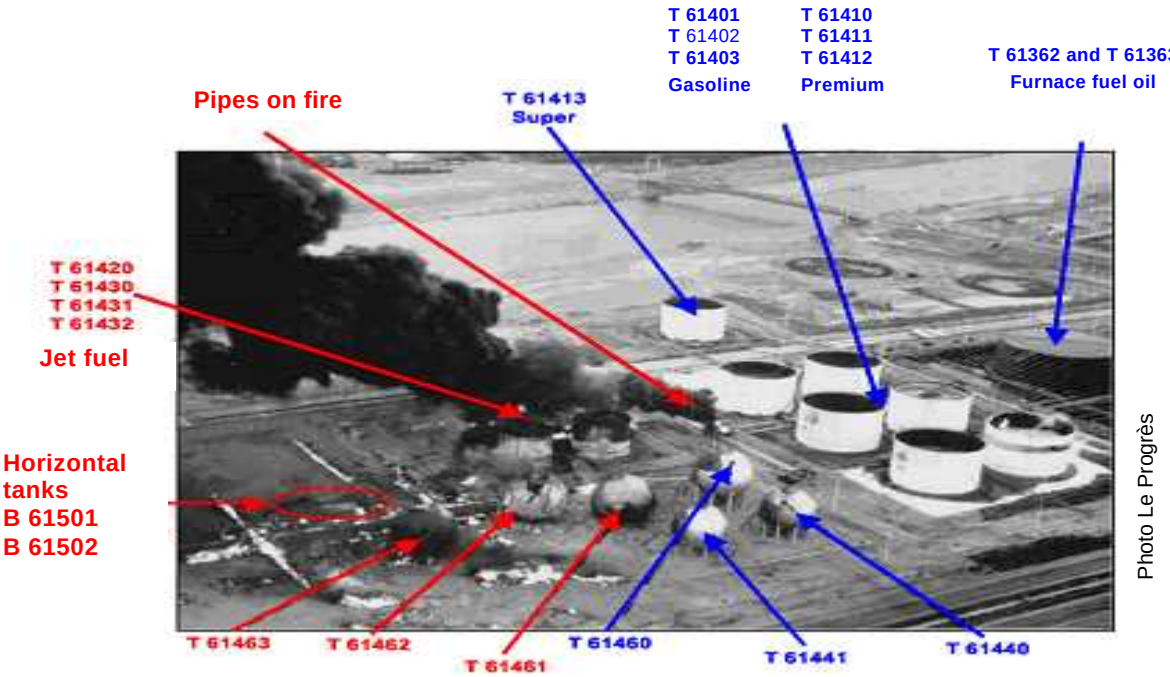


Photo Le Progrès

Figure 7 – Summary of property damage

Spheres:

Sphere 463 - butane

This sphere has a 4.50 m-long slit in the metal portion in contact with the gas phase. Based on the fragments recovered, it is difficult to affirm whether or not the valve had operated.

The sphere collapsed following the creeping of the unprotected part of its legs: the sphere was practically full.

Photo Le Progrès

Figure 8
Opening in butane sphere T 61463

Sphere 462: butane

The sphere opened up in the zone where the metal was in contact with the gas phase and the sheeting was ripped back over 7 m. The valve had functioned.

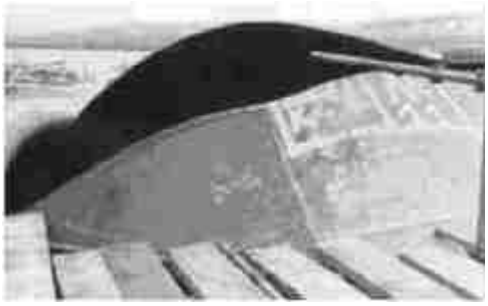


Photo Le Progrès

Figure 9
Opening in butane sphere T 61462

Sphere 461: butane

This tank exhibits ripping tears in numerous directions (3.50 m in length). The valve had functioned.

Subsequent metallurgical analyses conducted on the tank showed that temperatures exceeded 700 °C in some places.

The three spheres, 440, 441 and 460, were damaged but not destroyed. The zones of thermal radiation are indicated on the diagram opposite. A description of the damage to each of the spheres is provided below.

Photo Le Progrès

Figure 10 – Opening in butane sphere T 61441

Sphere 440 (propane)

The paint was burned over 1,200 mm on the SW face. The legs were moved and the fire-resistant cement had cracked. The SW face of the sphere was struck by a projectile.

Sphere 441 (propane):

The southern face was exposed to the flames.

The following elements were destroyed: the support legs, access means (ladders,..), several tubes in the lower section and notably the propane line to the shipping platforms: the sphere was completely emptied.

Three sheets were dented on the lower dome (0.16 m² and 4 m²) and sag of 30 and 15 mm.

Some of the damage was caused by the accident and by the sphere being filled with water during the post-accident degassing operations.

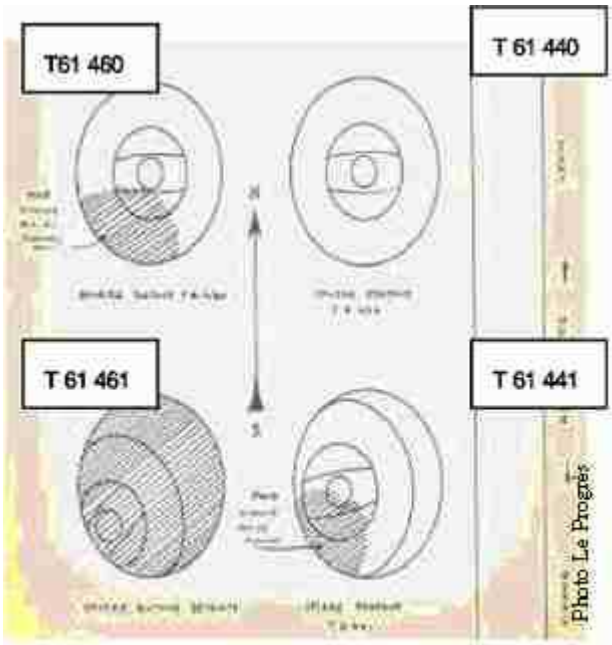
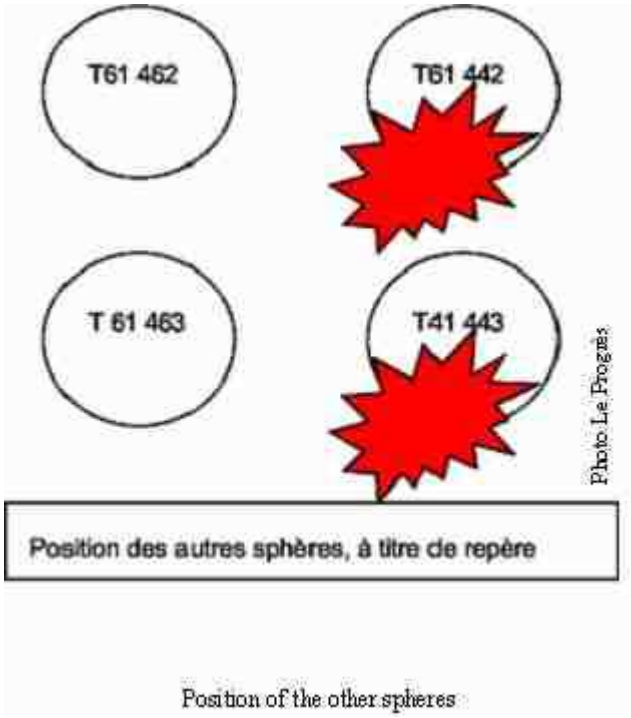


Figure 13 – Zones of spheres damaged by the flames and final position

Sphere 460 (butane):

The upper metal sheets were heat at an angle of 150° (which corresponds to the part in the gas phase). The fire-resistant cement of the support legs cracked, although the legs did not move.



Position of the other spheres

Photo Le Progrès

Figure 14 - Illustration of the general condition of the spheres damaged in the explosions

Horizontal tanks:

The "jet tanks" were damaged. In both cases, the metal was heated to very high temperature, then poorly cooled, which caused:

- deformations in the propane tank,

- an opening in the butane tank.

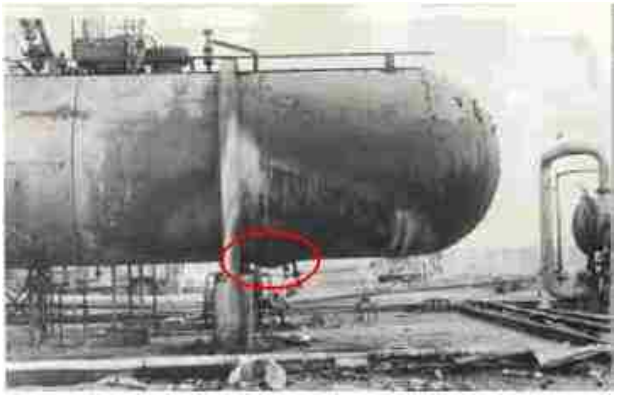


Photo Le Progrès

Figure 11 – Bulge underneath jet tank B 61502 (propane)

Piping:

This photo shows the condition of the hydrocarbon lines (essentially fuel, FFO,…) located near the motorway over-pass. According the reports compiled at the time of the accident, the destruction was essentially caused by flying debris from the exploding spheres.

Photo Le Progrès

Figure 12 – Pipe damage

Fragments and projectiles:

The propane spheres 443 and 442 exploded violently; fragments of all sizes were found in a radius exceeding 800 m. The largest elements, certain weighing more than 80 tons, were thrown nearly 270 m from their original location (see table 3).

	Sphere T 61442			Sphere T 61443				
Projected elements	**A1**	**A2**	**A3**	**B1**	**B2**	**B3**	**B4**	**B5**
Dimensions (m)	19 x 21.5	10.5 x 18.3	12.6 x 14.5	10.5 x 15	4 x 3	4.2 x 11.5	16.8 x 18.2	10.5 x 17.5
Estimated weight (T)	88.2	47.7	53.1	48	2.8	18	79	37
Distance (m)	138	325	222	85	82	228	248	270

Table 3 – Characteristics of the projected elements

Source: Institut Français du Pétrole

The spheres' valves were found in the following conditions:

- sphere T 442: one valve open, the other closed, both thrown approximately 800m and found completely exploded.
- sphere T 443: one valve open, the other closed, both thrown approximately 600 m and found assembled.

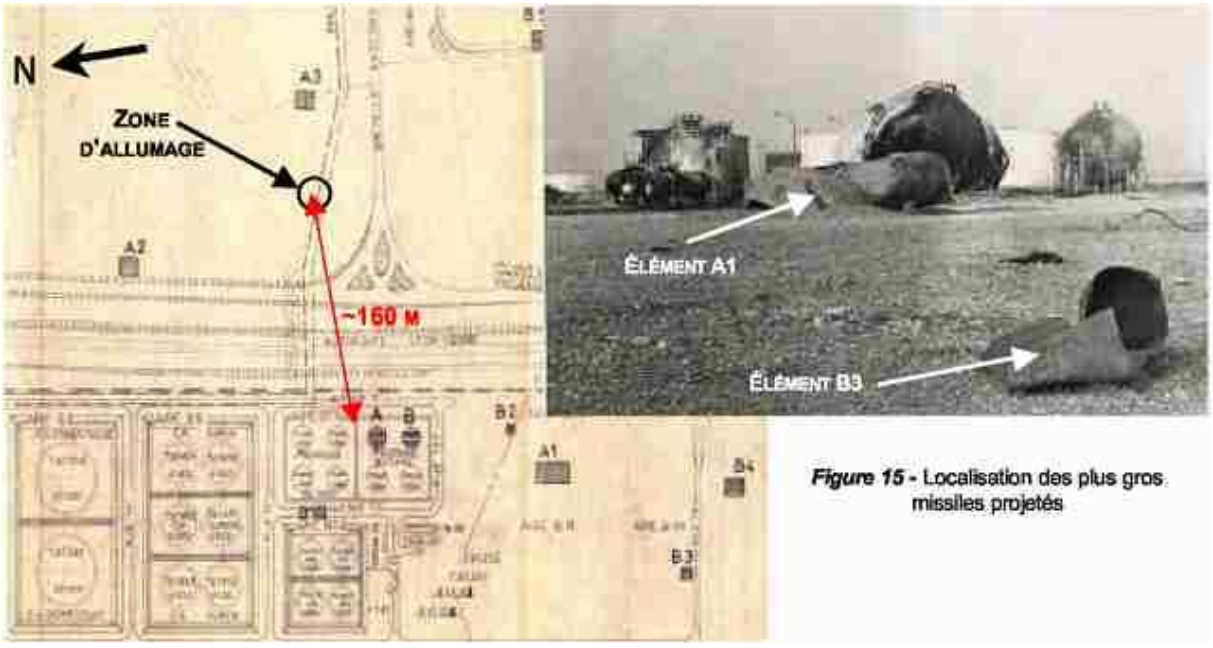


Figure 15 - Localisation des plus gros missiles projetés

The diagram below shows the 69 fragments and projectiles recorded and resulting from the explosion of the 2 spheres

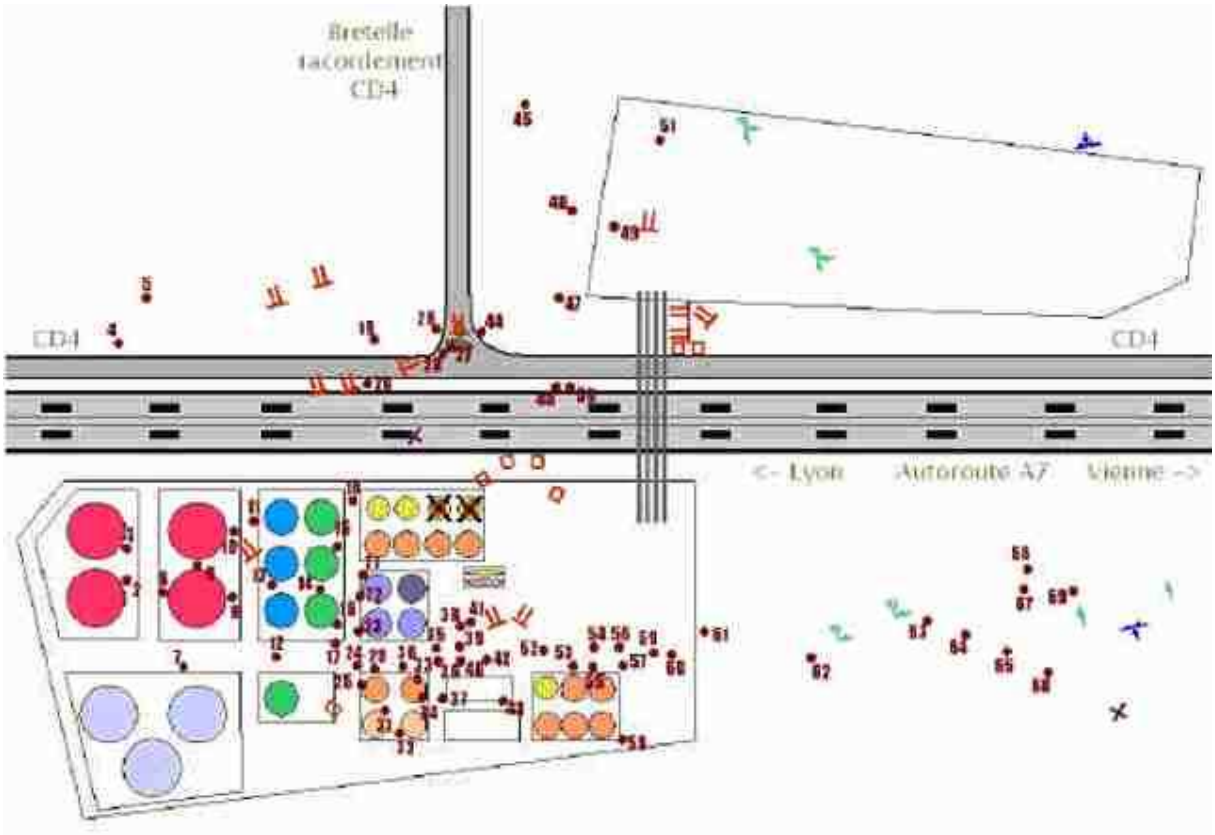


Figure 16 – Diagram showing the location of debris and accessories from the exploded spheres

Domino effect:

The damaged spheres show signs that some of them had been struck by elements from the spheres that experienced a BLEVE. By the same token, it appears that the racks of flammable liquid pipes (see photo) were struck by projectiles.

The flammable liquid storage zone was also significantly damaged

Overpressure effects:
Pronounced directional effects toward the south are noted along the Rhône Valley: roofs damaged 2.2 km away, walls moved at distances up to 4.2 km and windows broken further than 8 km away. The blast from the explosion was felt as far away as VIENNE (approximately 16 km upstream from the refinery): doors opened,…

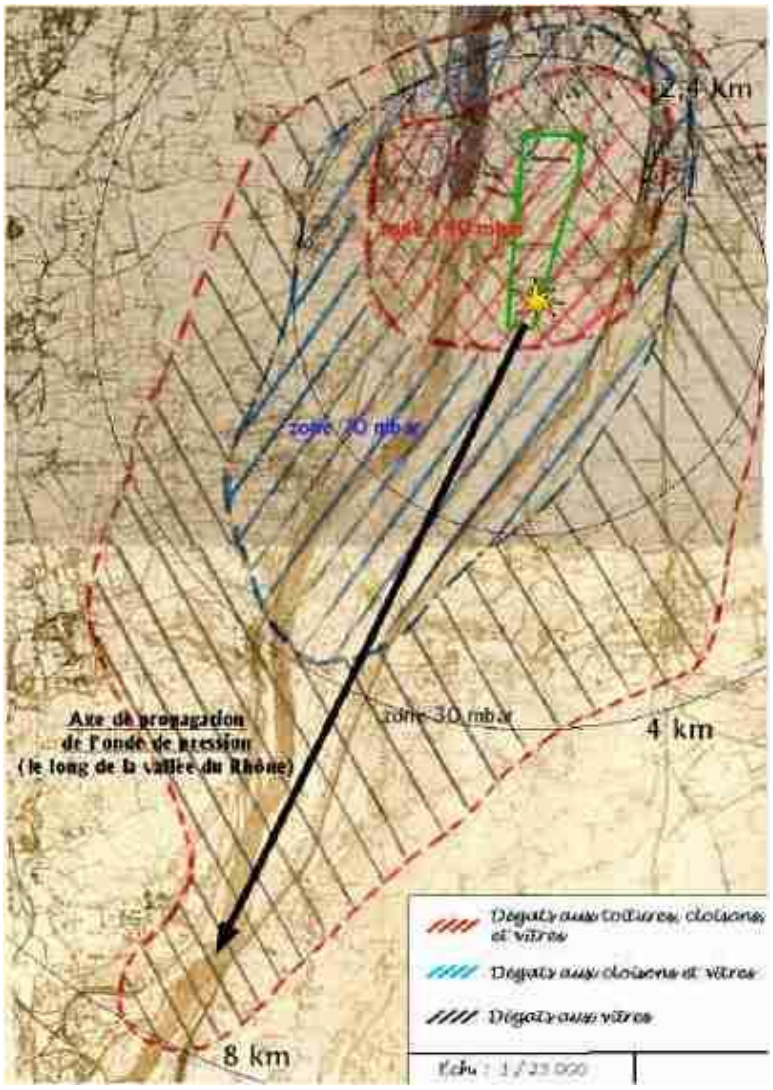


Figure 17 - Overpressure effects / Distance of property damage
Source: DHYCA

ORIGIN, CAUSES AND CIRCUMSTANCES OF THE ACCIDENT

Leak:

According to data provided by the Lyon Bron weather station, the conditions on the day of the accident are as follows and correspond to calm atmosphere:

- January 4, 1966, from 5 am to 6.35 am, wind from the south from 1 to 2 m/sec.
- January 4, 1966, from 6.35 am to 6.55 am, the wind turns to the east and varies from 1 m/sec. to 2.5 m/sec.
- January 4, 1966, from 6.55 am to 7.20 am, the easterly wind blows from 2 to 2.5 m/sec.
- Starting at 7.20 am, the wind was blowing at less than 1 m/sec.

It should be noted that the site is also protected to the east by upper reaches of the village of Feyzin.

The temperature was 5°C.

According to witnesses and to the condition of the valves of the purge system found following the accident, it appears that the upstream valve was wide open and the downstream valve was half-way closed.

The experts called in testify after the accident made various approximations regarding the flow rate of the leak from these various devices based on various information that they were able to recover, as far as possible.

1- Leak calculation for the 2'' branch connection:

[0.82.S.(2gh)$^{1/2}$, i.e. 11.5 kg/sec. considering the flow was reduced: 8 kg/sec.

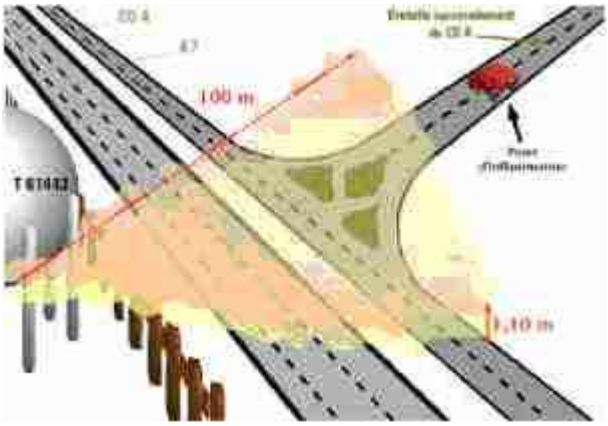


Figure 18 A highly schematised representation of the cloud according to witnesses

2 – Estimation of the quantity lost until the gauge blocked:

At 5 am, the sphere contained 693 m^3. The sphere's gauge, found after the explosion, was blocked at 647 m^3, resulting in a difference of 46 m^3 (approximately 23 t). This is a minimum difference as the sphere was still being supplied when the accident occurred at 6.40 am, roughly an hour and 40 minutes after its capacity had been recorded.

The gauge may have become blocked either when the explosion occurred (approximately 2 h after the leak started) or, as indicated by the technicians, when the gas leaving the valve ignited (the temperature would have damaged the measuring device and the leak time drops to 1 h). In this last case, the minimum leak flow rate (certainly under-estimated) is 6.4 kg/sec.

3 – Dimensions of the cloud observed by witnesses:

The report compiled by the *gendarmerie* at the time of the accident includes the following elements: a gas could formed in a maximum of 30 minutes, covering approximately 3.8 ha and measured roughly 1.5 m thick.

This corresponds to a gaseous mixture estimated, at that time, to be 40,000 m^3, or 68 t (37 kg/s): the court-appointed experts considered this value to be extremely high as the visible part of the cloud (having a "milky-white" colour) corresponds to the condensation of water vapour in the air and not "pure" gas.

4 – Brief estimation by the operator:

Opening of the purge line: 30 to 40 t/h, i.e. between 8 and 11 kg/sec.

BLEVES:

The two explosions on propane spheres 443 and 442 are classified as BLEVE (Boiling Liquid Expanding Vapour Explosion). At the time of the accident, this phenomenon was not or poorly known, both within the profession and within the emergency services.

The models shown below, built following the accident, show the fragments that were projected when the 2 spheres exploded.

1st BLEVE:

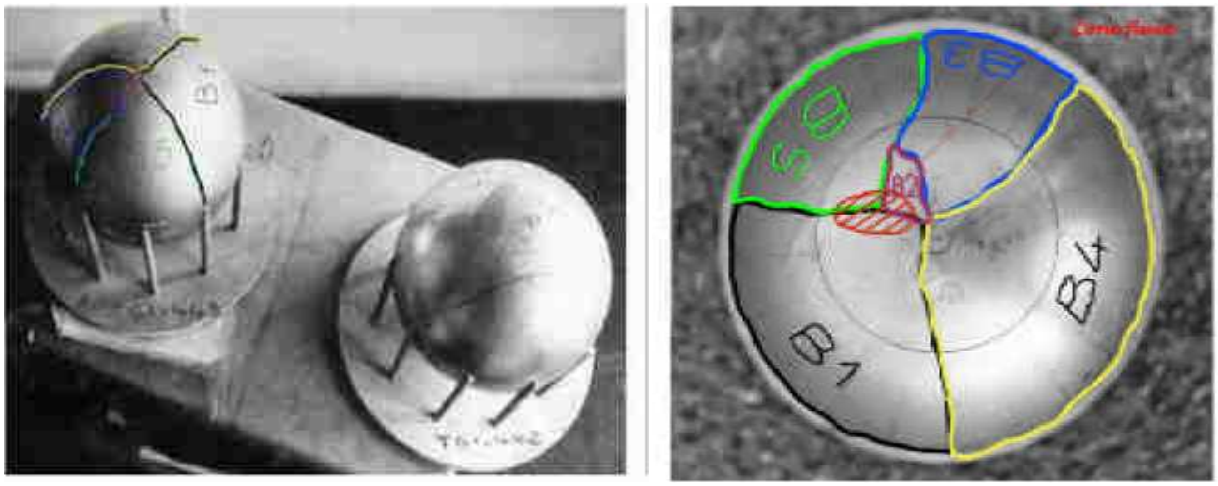


Figure 18 – Model of the main fragments of sphere T 61443

The explosion occurred approximately 2 hours after the leak began and 1½ hour after the cloud irrupted into flame.

According to period documents and particularly the photos, it appears that the sphere was entirely "engulfed" in flames. The propane had reached a height of 7.12 m at 5 am, with a diameter of 13.27 m. In fact, the sphere was being filled: it thus continued to fill until the flow stopped (7.30 am?), or for 2½ hours after the height estimation. The leak then occurred via the 2'' pipe for approximately ½ hour. Beyond this time delay, the valve was opened up until the time of the accident (for 1½ hour). (rough estimate of the quantity lost: 80 t + 105 t – there remained at least 160 t, although certainly more, in the sphere at the time of the accident).

According to the data collected, the sphere's cooling system had not been activated as the spray control was located in a zone where it rapidly became inaccessible due to the high temperature.

The fireball reached 250 m in diameter and rose to height of more than 400 m.

The metallographic examination indicated that the upper zone (see figure 18) had yielded: the temperature had reached around 800 °C.

2nd BLEVE

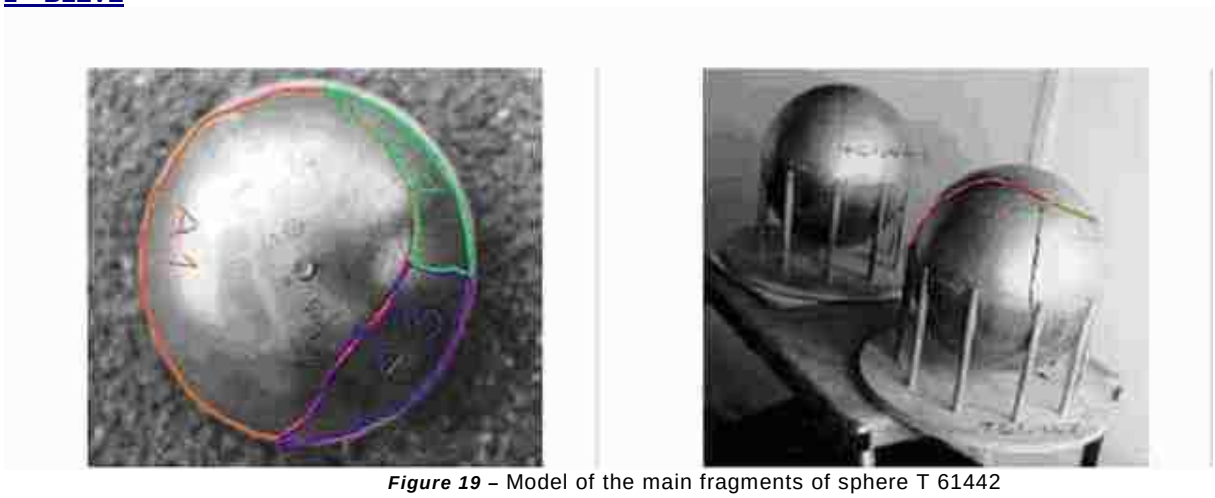


Figure 19 – Model of the main fragments of sphere T 61442

The propane had reached a height of 8.47 m at 5 am, with a diameter of 13.27 m. This sphere was cooled down by its fixed cooling systems starting at 7.20 am.

Few elements are available which describe this phenomenon. However, the explosion created a large crater underneath this sphere (see figure 6).

According to the hypotheses formulated after examination of the impact points and the various fragments recovered, piece B1 from the 1st Bleve (sphere 443) probably damaged the east legs of sphere 442, thus causing it to topple over. The pipes on the lower section of the sphere were broken at that moment.

Causes:

The expert's report mentioned various possible avenues of investigation, some representing potential causes while others are in form of recommendations for extensive improvements based on numerous findings and testimonies collected at that time. For convenience purposes, they have been grouped together by themes.

Sampling devices on the lower section:

Their overall operation was examined in conjunction with the technical characteristics and the testimonies of the persons concerned.

Formation of an ice plug: Based on the chronology of events, during the manoeuvre, the lower valve is opened. The upper valve is then opened, then the flow stops. The opening of the upper valve wide open results in a massive leak of product a few seconds later. The operating lever exited the stem square; the operator fails to replace it and steps back. The freezing of the valves then prevented them from being operated.

The experts explain the phenomenon as follows; the expansion that occurs at the upstream valve when the upper valve was initially actuated (reminder: upstream valve already open) caused the humidity present to solidify and form a block of ice. The ice blocked the pipe, allowing no liquid to flow out. The operator's action (opening the upper valve completely) perforated the block of ice and resulted in the massive leak.

Lubrication:

The expert evaluations conducted on equipment recovered approximately 200 m from the sphere determined that the valve had very little lubrication although the low temperature was favourable in making it easier to operate. It was found completely open.

The downstream valve also had very little lubrication but according to the testimonies, it was easy to operate. It was found ½ open.

According to the experts, even if maintenance does not appear to be optimum, the theory of poor lubrication did not effect the manoeuvres performed at the time of the accident. Generally speaking, they nevertheless recommend that the maintenance of the equipment be monitored and logged. The use of low-maintenance valves (not requiring lubrication) was proposed.

Operation: tapered plug valves are known to be ice-breakers; in this case, the upper valve fulfilled this role by perforating the block of ice that formed in the purge pipe during the drainage operation, resulting in the leak that was observed.

Control by square wrenches: The site decided to implement a nut device designed to lock the valve in the desired position while the manoeuvres are being performed, while preventing the operating levers from falling. In the case of sphere 443, the device was not in place.

Purge lines: Their diameter was determined to be excessive in relation to the objectives sought.

Positioning of the assembly: according to the testimonies, the sampling valves was not always easily accessible, particularly in the case of this sphere. The experts recommend that sufficient space be left under the spheres to perform the manoeuvres (free of all piping or other equipment, vertical clearance of 3 m).

Operation:

On August 6, 1964, a leak occurred under butane sphere 462. The wrench was dripped during the manoeuvre. The leak was brought under control, although with difficulty. The same situation occurred February 26, 1965, under propane sphere 441.

Following these two incidents which occurred during the first 2 years of operation and thus prior to the accident of January '66, operating procedures were drawn up taking which took into account the lessons learned, from the technical standpoint: the sampling or purging operations must be performed by first opening the upper valve (one-fourth), then the lower valve is opened *"progressively and never completely"*. The principle is to open the upper valve slightly, then adjust the purge using the lower valve. In this manner, if an expansion phenomenon occurs with sudden cooling, the upper valve remains operational.

Overall, the lessons learned from past events relative to the human factor (clarity and the respect of instructions, improvement of the access and operating conditions) were not used and no constructive modifications were made.

Manual manoeuvre on the day of the accident:

The manoeuvre was performed in reverse order and, in addition, the upper valve as opened excessively.

Retaining catchpits:

The report stipulates that the size of the catchpits be reviewed in relation to the criteria of the period.

Valves:

If compliance in relation to the standards applicable at the time of accident is mentioned by the experts, they raise the question as to the sphere's resistance to the valves' adjustment pressure, in case of significant overheating. The recommend cooling of the spheres, particularly on the upper section.

Cooling of the vessels:

Independently of the conclusions, the lack of water resources was recorded and mentioned. Reinforcement of the fixed tank cooling systems is recommended.

"Isolation" of the site:

The fenced enclosure, along the motorway side, was not replaced by the solid 2.50 m wall stipulated in the building permit and requested several times by the emergency services.

The strategy and organisation of internal and external emergency services:

The external rescue services were insufficiently informed of the risks and poorly trained in countering them. Furthermore, the lack of a singular command point coordinating the action of the various entities and services was felt.

ACTION TAKEN

On April 28, 1970, the judgment by the Magistrate's Court of Vienne recognised the penal responsibilities in the death of the driver whose car ignited the cloud of gas. The individuals blamed include the helper and the security agent (for negligence and a misunderstanding of the safety instructions), as well as the both the company's and refinery's General Managers (as the fenced enclosure had not been replaced – along the motorway – by the solid 2.50 m-high wall foreseen in the building permit and requested repeatedly by the emergency services). Furthermore, the Director of the refinery and the Captain of the fire brigade are named as being responsible for the deaths and injuries among the rescue personnel. Suspended prison sentences were passed (from 6 months to 1 year), in addition to fines. In terms of civil responsibility, approximately 1 M French Francs in damages is to be borne by the accused.

LESSONS LEARNED

In France, the FEYZIN catastrophe remains one of the most deadly and memorable catastrophes in recent industrial history.

This accident led to extensive reform of technical regulations applicable to petroleum installations. The Ministerial Order of September 1967 (modified in 1973 and 1975) concerning refineries, is the result of work undertaken by a commission formed by the administration and the profession and defines the new provisions, such as :

- ✓ A new classification of liquid and liquefied hydrocarbons dealing not only with ignition criteria, but with treatment and storage conditions: reheated product, product liquefied under pressure,...
- ✓ The definition of dangerous or danger-prone zones around petroleum installations– types 1 and 2 depending on whether combustible vapours appear during normal operation or in abnormal conditions.
- ✓ The assignment of location rules and notably the distances to be respected between the installations themselves as well as in relation to external third-parties (homes, roads, public buildings),
- ✓ The definition of new rules regarding the design and dimensioning of the catchpits associated with the liquid hydrocarbon storage tanks.
- ✓ The definition of new rules for liquefied hydrocarbon storage equipment, notably regarding their purge line and overpressure valves, now designed in the hypothetical situation of a widespread fire.
- ✓ The definition of new design rules for fire fighting equipment, for the liquid hydrocarbon storage facilities and liquefied hydrocarbon storage tanks: these rules deal with the extinguishing of the fire (water and foam concentrate) and the cooling of adjacent installations.
- ✓ The publication of general safety regulations (elementary safety rule and actions to be performed in the event of an accident) and instructions relative to manufacturing, maintenance operations and work (including burning permits) and the inspection of equipment.
- ✓ An organisation plan for fire fighting and rescue operations must be drawn up by the head of the establishment alone inasmuch as the ORSEC plan (which became the "special intervention plan (PPI) for industrial establishment) has not been put into action by the Préfet.
- ✓ The application of certain new rules concerning the existing installations and with retroactive effect in fixed deadlines.

Concerning hydrocarbon depots, the old rules of 1948, which were modified several times, were replaced by the Ministerial Orders of November 9, 1972 (modified in 1975) relative to liquid hydrocarbons and to liquefied hydrocarbons. The new rules are directly inspired from refinery regulations and feature the same innovations schematised above, transposed to the specific case of petroleum depots. This reference remains even if, more recently, specific safety rules were passed by Ministerial Order of November 9, 1989 for existing liquid hydrocarbon stations and by the Ministerial Order of May 10, 1993 relative to existing liquefied hydrocarbon station.

The 2 other main non-technical changes are as follows :

- ✓ Locally, a certain number of communities to the east and south-east of Lyon (including FEYZIN) which were included in the Isère *département*, were assigned to the Rhône *département* in late December 1967.
- ✓ The *Service des Mines* was assigned the control of the refineries under the terms of the Act of December 19, 1917 concerning dangerous and polluted establishments. In the early 1970s, the inspection of Classified Installations which was performed by the Labour Inspectorate, was transferred to the *Arrondissements minéralogiques* (which has since become the DRIRE).

Bibliography (main sources):

- The internal magazine of the greater Lyon region, Grand Lyon, No. 50 of December 1996
- Report of the court-appointed experts compiled following the accident,
- *Service des Mines* report – Isère subdivision – No. 05460 of Jan. 2, 1967
- Report of the Feyzin refinery accident which occurred January 4, 1966, dated January 19, 1966- DHYCA
- Le Progrès