# Explosion of a hydrogen tank

## 1st October, 1988

## Saint-Fons (Rhone)

## France

**Pressure equipment**
**Explosion**
**Failure (equipment)**
**Hydrogen**
**Corrosion**

## THE FACILITIES INVOLVED

### The site:

The plant is affiliated with a French group synthesising chemical products and pharmaceuticals. The site employs several hundred people and is located on several dozens of hectares along the banks of the Rhône River, south of Lyon and near the Feyzin refinery.

### The facilities:

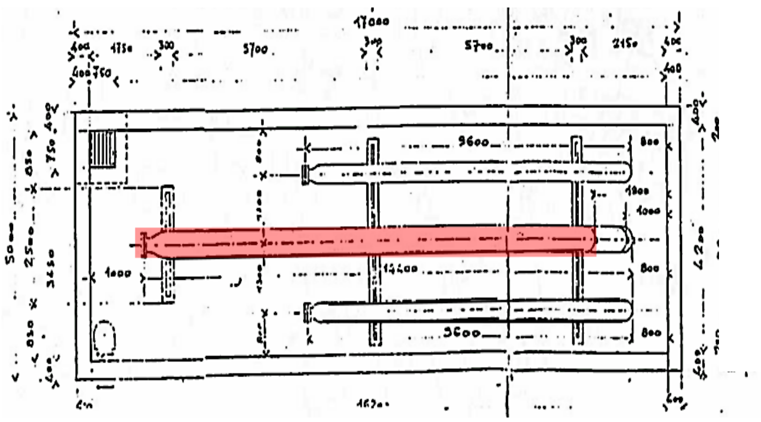
The unit involved is a hydrogen ($H_2$) storage facility that supplies several workshops. The gas, produced in a nearby plant, passes through a 70 m³ buffer tank, which supplies the storage facility via a pipe at 35 bar. The $H_2$ is compressed at 150 bar before being stored in 8 'cigar' cylinders (35 m³ in all). These cylinders can be isolated from the rest of the supply system by a pneumatic valve that closes automatically in the event of an emergency or upon an air supply failure.

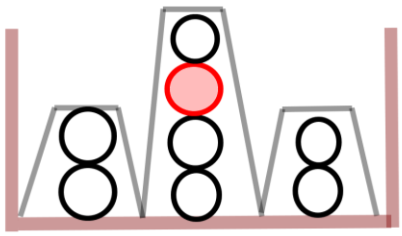
The tanks are installed in a concrete pit dug into the side of an embankment and which is protected by a fibre cement roof of the following dimensions:

- Length: 17 m
- Width: 5 m
- Height: 3.6 m (buried portion: 2.2 m)
- Distance to the nearest building: approximately 15 to 20 m
- Distance to the dual carriageway: 350 m

Characteristics of the cylinder involved in the accident:

- Outside diameter: 0.57 m
- Wall thickness: 12.6 mm
- Length: 15 m
- Volume: 3 m³ (3000 litres)
- Operating pressure: between 120 and 150 bar (accumulator use)
- Last hydraulic test of the cylinder: 1985 at 225 bar
- Material: standard steel with density of 7,850 kg/m³
- Forged in 1939 by a German manufacturer.





Top and front views of the pit

The cylinder was in the middle of the pit and above 2 other cylinders

## THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

The event occurred on a Saturday morning, at around 6 a.m. The plant was thus practically empty, although the chronology of the accident can nevertheless be reconstructed from the testimonies of the few operators who were present at the time:

### Phase 1: Gas leak

Loud whistling from the hydrogen storage facility could be heard at 6:05 a.m. and lasting 20 to 40 seconds.

### Phase 2: Explosion

The cloud of $H_2$ ignites. A very bright, red-orange fireball measuring 15 to 20 m in diameter was visible between 6:05 and 6:08 a.m. Witnesses in a break room, located 100 m away from the pit, felt the shock wave and the heat from the blast. The hydrogen in the associated tanks also burned until completely depleted.

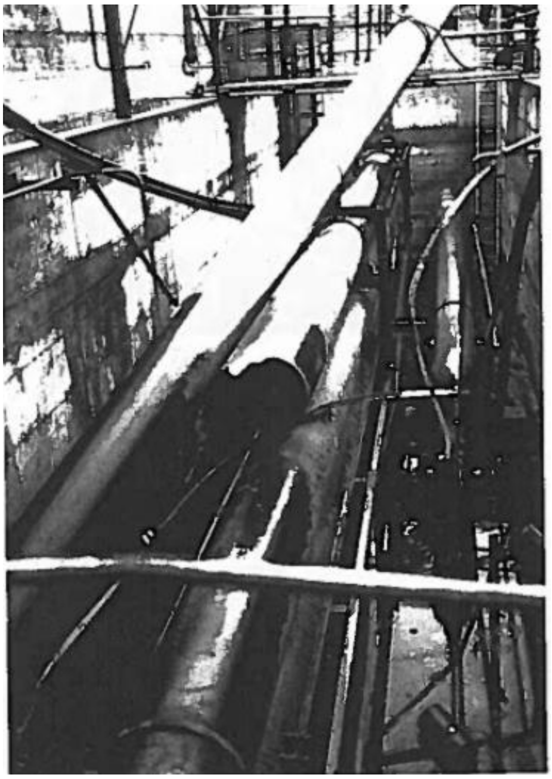
### Phase 3: Emergency response

The fire brigade was called, and the unit was shut down via an "emergency stop" switch at 6:08 a.m.

The following was noted upon the arrival of the first responders:

- Approximately 2/3 of the pit was on fire;
- A flame front ranging from 3 and 4 m in height.

The pit was flooded with foam. The $H_2$ line supplying the storage facility was isolated.



View of the pit after the accident and the cylinder reconstructed for expert appraisal - 

### Consequences of this accident:

Had the explosion occurred at a less favourable time, it could have resulted in physical injuries off site. The blast effect of the explosion resulted in property damage:

- Broken windows and store fronts up to 515 m away;
- Damage to building cladding, walls or ceilings up to 350 m away;
- Displaced roofing tiles up to 280 m away.

Thermal effects of the fireball were virtually nonexistent:

- Burn marks on supports, cylinders and the metal uprights of the storage tank roof;
- Temperature rise (even slight russeting) of the dry foam lining the wall of the nearest workshop.

Ten or so cylinder fragments were found after the accident: 6 in the pit and 2 outside the plant (up to 150 m away). One of these fragments severed the compressed air line supplying the storage facility's isolation valve.

Propelled to the side opposite its rupture (toward Saint-Fons), the exploding cylinder collided the pit's east wall, and then flew back in the opposite direction.

## 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 for hazardous substances and in light of available information, this accident can be characterised by the following four indices:


The 'Dangerous materials released' index is level 2 owing to the amount of broken glass observed between 330 and 700 m away (parameter Q2). The other indicators are blank since no environmental impact of the accident was identified. No human casualties have been identified. Lastly, the total cost of the damage is unknown. As such, the 'economic consequences' indicator is not completed.

The parameters associated with these indices and their rating scale are available at the website: http://www.aria.developpement-durable.gouv.fr.

# THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THIS ACCIDENT

Hydrogen embrittlement of the steel was the first assumption to explain the fast failure of the pressure vessel in the 1st quarter of its length (valve side). The damage observed on the facilities can be explained by the potential energy stored in the cylinder (Potential Energy = Pressure x Volume) and its sudden release at the moment of rupture (pneumatic explosion). On the other hand, a model based on the TNT equivalent of the mass of $H_2$ contained cannot explain the observed damage.

An expert assessment attributed the accident to a time-dependent rupture (static fatigue) of the cylinder resulting from $H_2$ embrittlement of the steel on the front support cradle. The cylinder was recycled, having already been used at other sites, notably as a nitrogen storage tank. The various documents in the pressure vessel's file give no precise indication as to the type of the metal used in its construction.

The metallographic analysis laboratory noted several factors that contributed to the cylinder's rupture:

- The **relatively high characteristics of the steel** (Rm > 1,000 MPa);
- The presence of **acicular martensite**, synonymous with tempering heat treatment performed at low temperatures, while **structures adapted to the hydrogen are somewhat globular**, obtained with heat treatments at high temperatures;

Acicular martensite structure of the cylinder's steel after etching with Nital - 

- The surface of the cylinder's inner wall has **pitting**, and even **corrosion craters**. The surface roughness resulting from this condition increases the surface area of the steel in contact with $H_2$ and facilitates the absorption of this gas. The depth of the pits also results in a local increase in stresses (notch effect, decrease in the cross-section where the forces are applied).

**A closer look at hydrogen corrosion:**

- The diffusion of hydrogen through steel causes embrittlement whose severity increases with the mechanical strength of the steel;
- Hydrogen diffuses into metals in its atomic form;
- The concentration of hydrogen atoms depends on the temperature and pressure;

Three phenomena are encountered depending on the temperature:

- Above 200 °C (high temperature), decarburization of the steel with intercrystalline cracking;
- At low temperature: Decreased deformation capacity and increased risk of rupture;
- Hydrogen blistering.

## ACTIONS TAKEN

For economic reasons, the activity of the units connected to the storage facility was quickly resumed. These units were supplied directly via an existing 35 bar line. Before commissioning, the piping underwent a leak test with helium followed by a hydraulic test coupled with a dye penetrant inspection to search for external cracks. Impact tests (resiliency) and crystallographic examinations in addition to these tests. All the examinations showed no traces of hydrogen embrittlement.

Following this event, the Classified Facilities Inspection authorities identified similar storage facilities in the Rhône-Alpes region. Special attention was given to older equipment and their history, as well as the characteristics and composition of the steel. Nearly 80 internal defects were detected on one of the site's hydrogenation units (made of Hastelloy alloy) where the explosion occurred.

Apart from the inspections carried out on the site, the operator is also developing new operating procedures for its hydrogen piping. These procedures notably concern the following:

- Secure shutdown in the event of a problem (burning of hydrogen to reduce the pressure to 1 bar, followed by flushing with nitrogen);
- The hydrogen pressurisation phase.

Two automatic shutoff valves slaved to independent pressure gauges are installed to protect the supply line on a hydrogenation unit.

**Method used to inspect the hydrogenation units with regard to the risk of hydrogen embrittlement:**

- Hardness measurement of the inside wall;
- Internal and external metallographic replicas;
- 100% examination of welds using the eddy current method;
- Ultrasonic examination (mesh size: 50 mm x 50 mm) to detect internal defects.

## LESSONS LEARNT

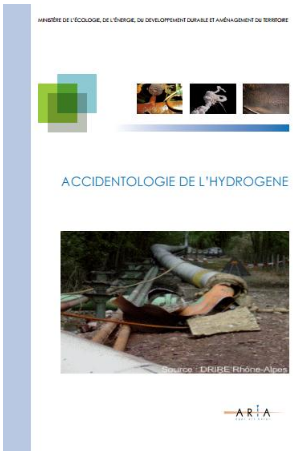
Several factors contributed to the hydrogen embrittlement of the steel in the Saint-Fons accident:

- The pressure that accentuates the absorption phenomenon activates the hydrogen on the surface of the steel;
- The purity of the hydrogen gases used could even be a determining factor that triggers the hydrogen embrittlement phenomenon. The gas used on the site had a very low oxygen content (0.5 ppm) which can aggravate the hydrogen embrittlement phenomenon. Oxygen helps inhibit this phenomenon;
- The level of stress of the cylinder's casing against its support structure, the cylinder being used as an accumulator;
- The characteristics of the cylinder's steel;
- The very small size of the hydrogen molecule which can diffuse easily and the very different conditions between the first use of the tank ($N_2$ storage) and its use in the factory ($H_2$ storage).

These points underscore the importance of preparing pressure equipment files, notably regarding the characteristics of the steels used. It is worth collecting this information, particularly for older equipment. Failing this, their replacement should be considered. Furthermore, it should be ascertained whether their recycling as part of a new process poses no problem.

Lastly, the operating conditions for a pressure vessel, particularly when used as an accumulator tank, should be analysed in light of the fatigue phenomena.

For further information about controlling the risks associated with hydrogen, a study and a list of accidents can be downloaded at the following address:

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