# Fire and Explosion of LPG Tanks at Feyzin, France

【January 4th, 1966　Feyzin, France】

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This accident brought about an enormous disaster resulting from a small human error. The details of the accident show well the dangers of handling LPG (Liquefied Petroleum Gas) and force us to carefully consider the location of large tanks of LPG. Furthermore, it is the first accident in which the phenomenon of BLEVE was made clear.


In the early morning of January 4th, 1966, a large-scale explosion and fire accident of LPG occurred in the Feyzin refinery of the France national petroleum

company at Feyzin in the suburbs of Lyon in the southern part of France. Three operators opened two 2-inch valves, which were mounted in series at the bottom of a 1200m$^3$ propane spherical tank. Due to some problems, the valves did not close, and LPG escaped. Because LPG is heavier than air, it spread along the ground as a cloud of vapor to the highway at a distance of 60m and the local road parallel to the highway. The traffic on the highway was stopped, but the traffic on the local road was not stopped. The escaped LPG caught fire by a car passing through the local road and exploded. The fire reached the tank from which the LPG first leaked, and explosive destruction, called BLEVE, of the tank vapor phase was caused by the tank fire. The fire spread to five other LPG tanks in the same tank yard and also damaged many tanks of crude oil, and other materials that were near. It is said that eighteen persons died and dozens of persons were injured, but in another estimate, a maximum of 81 deaths and 130 injuries was given. The monetary damage was said to be about 18 million US dollars at the time of the accident (70 million US dollars in 1990 dollars).

LPG is the most dangerous fuel that is made from petroleum. In this accident, the remarkable characteristics of LPG appeared. The dangers of LPG include the following. a) LPG can travel along the ground for a long distance, because the vapor specific gravity is greater than air, allowing the formation of a “vapor cloud”. b) As a result of the equilibrium relationship between the vapor pressure and the temperature, an extremely low temperature results when the pressure drops. c) A special form of explosive destruction called BLEVE is caused in the fire of a storage tank. Since the gas form of LPG is colorless and odorless, an explosion may occur though the leakage is not noticed, although this was not the case in the accident of Feyzin. These dangerous characteristics of LPG are the same for the general consumption as for industrial use.

BLEVE: The abbreviation of “Boiling Liquid Expanding Vapor Explosion”, an explosion phenomenon caused by the rapid phase change (vaporization) of a liquid. A liquid substance stored in a pressurized vessel is in a vapor-liquid equilibrium condition. When it is heated to a temperature that is sufficiently higher than the boiling point of the substance at atmospheric pressure, such as when the container is heated in a fire, the pressure also rises in the container. When the container is damaged under this condition and the gas escapes, the pressure in the container drops to atmospheric pressure in an instant. The equilibrium state in the container is broken at this time, and an explosion phenomenon results from the bumping of the liquid that is rapidly changed into the gas phase. This is called BLEVE.

The BLEVE phenomenon that occurs in the LPG tank was shown in Fig.1. First,

a fire was generat ed under the sph erical tank. The LPG in the tank w as heated, and the tank internal press ure rose. The LPG vapor was discharged to the atmosphere when the internal press ure rose above the s etting pressure of th e safety relief valve, and this vapor caught fire. Th e surface of the wall above t he liquid l evel was strongly heated, causing the strength of the wall to deteriorate. Finally, the wall ruptured under the internal pressure. As a r esult of the rupture, the pressure inside the tank dropped to atmo spheric pre ssure instantane ously, and the BLEVE phe nomenon happe ned. The large vapor that resulted became an enormous fireball.

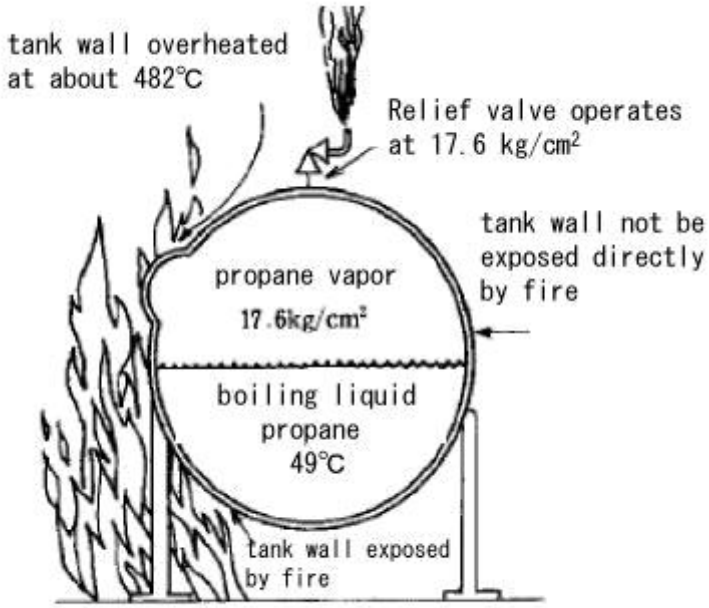


Fig.1 Explanation of BLEVE

## 1. Event

On J anuary 4th, 1966, at the Feyzin refinery in the suburbs of L yon in the southern pa rt of F rance, th e valves c ould n ot close during work at a LPG spheri cal tank, which contained 1200kl propane, and a fire and explosion occurred from the leakage of LPG. The tank causing the accide nt was constructed in the tank yard where eight spherical tanks (four 1200kl propane ta nks and four 2 000kl butan e tanks) were located. There was anot her tank yard with four atmospheric pressure tanks containing 400kl of jet fuel (kerosene fraction) adjacent to the LPG tank yard.

Three operators opened the valves at the bott om of the LPG tank in order to drain the free water that had accumulated at the botto m. They finish ed the wor k in about 15 minutes, and they intend ed to close t he valves, b ut the valve s d id not close perfectly. There were two valves that were placed in series, and the upstream valve did

not close. They left the site without closing the downstream valve (or it could not be closed). The alarm (a gas detector) indicating the possibility of a gas leak rang in the control room, and a warning was issued in all of the Feyzin districts.

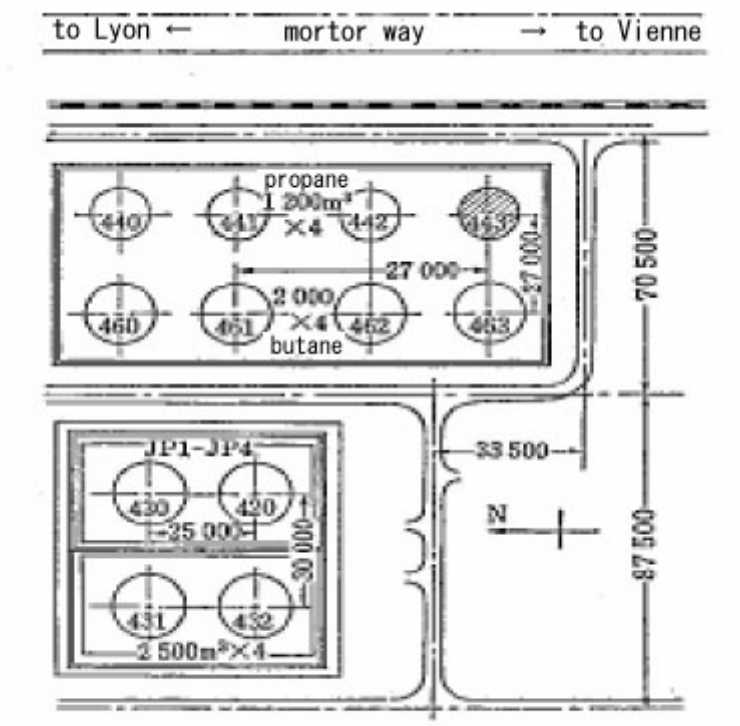


Fig. 2 location of the spherical tanks

In the meantime, the leaking LPG spread in the direction of the highway that was located 60m from the tank, while forming the vapor cloud. There was a small local road running parallel to the highway. The traffic on the highway was stopped, but the traffic on the local road could not be stopped. One car drove past on the local road. The driver recognized the gas flow and stopped the car several meters before the gas flow. However, an enormous flame happened at the moment, the flame flowed backward in the direction of the tank, and the leaking tank was wreathed in flames. The fire extinguishing work was carried out on the circumference of the flame by spraying water and fire extinguishing foam, and the adjacent spherical tanks were cooled by water from the water-spraying nozzle of each tank. However, the safety valve of the leaking tank operated, and the gas spouted out of the tank. The first accident tank exploded suddenly, and then the second and third tanks exploded. In addition, petroleum products, crude oil, and other materials caught fire, and it became a major disaster.

As shown in this accident, if leaked vapor diffuses to the atmosphere like a cloud

without igniting immediately then an explosion may occur. This phenomenon called "Unconfined Vapor Cloud Explosion", abbreviated as "UVCE".

## 2. Course

At 6:30, in the early morning, three operators started the water draining operation of the tank. The drainage flow rate is normally controlled by adjusting the downstream valve while the upstream valve is fully opened, but the actual method used on that day was not found recorded anywhere.

It appears that the draining work was finished after about 15 minutes. First, they tried to close the upstream valve. The LPG leak started because that valve was not closed completely. The closing of the second valve, the downstream valve, was not described. After a few minutes, they were wrapped in propane vapor, and they walked from the site unsteadily. The leaking LPG spread in the direction of the highway, with partially vaporizing. The alarm rang in the control room at this time.

At around 07:05, the alarm rang through all of the Feyzin districts. However, "all of the Feyzin districts" may mean just the "whole Feyzin Refinery", and it is not clear in the literature whether the alarm rang through the whole town or through the whole factory. The first fire truck of the factory turned out immediately. The fire brigade of Lyon arrived at 07:20. Apparently, at some time before the arrival of the fire brigade of Lyon, the traffic on the highway next to the refinery was stopped.

At a little before 07:30, a car came and stopped on the local road where the traffic had not yet been stopped. The explosion apparently occurred just after the car stopped. The fire increased in power, spread along the leaking LPG, and the tank was wreathed with flames immediately.

At 08:40, the first tank exploded by the BLEVE phenomenon after spouting LPG through the safety valve. The second and third spherical tanks exploded five minutes later. Two more spherical tanks and many oil tanks burned continuously.

In the next morning, the fire was extinguished at last.

## 3. Cause

### 3.1. Cause of the leakage

It seems that the leakage was caused by the freezing of the valve by the drain work. However, the freezing is a result and not a cause in fact. For LPG, in this case propane, the temperature drops to -40℃ if the pressure is lowered to atmospheric pressure. At this temperature, not only is the moisture in the air frozen, but the moisture also reacts with LPG, forming a solid hydrate. The hydrate formation does

not require an extremely low temperature. Apparently, either the valve handle was stuck by the frozen moisture or the valve could not be closed tightly as a result of the hydrate formation.

Considering the possibility of ice formation, usually two drain valves and sampling valves are mounted on the bottom of LPG tanks in series. An example of this situation is shown in Fig.3. The usual operation for opening the valves at the beginning of use is as follows. First, the upstream valve is opened fully, and the inlet side of the downstream valve is pressurized. Next, the downstream valve is gradually opened starting from the slight open, adjusted to create the necessary flow rate. Because the downstream valve inlet is pressurized, the temperature at upstream valve does not drop. The outlet side of the downstream valve is cooled under the operation, and it is also important to ensure that there is sufficient distance so that the upstream valve does not drop to a low temperature. This accident was believed to have been caused as follows: the upstream valve was not opened fully and the pressure at the outlet of the first valve was near the atmospheric pressure, so the upstream valve was cooled by the pressure difference. It is absolutely forbidden to operate valves like this. Therefore, the cause of the accident is either the operator's human error or a mistake on the management side in not to explaining the meaning and proper execution of the operation.

Moreover, another one of the causes is that the operator did not close the downstream valve. There is not a clear description of why this valve was not closed. It is presumed that either ice was generated in the downstream valve like in the upstream valve or a rapid large LPG leak occurred at the end of drain work. If a large LPG leak occurred, the operators may have panicked when they could not close the upstream valve and therefore may have not remembered to close the downstream valve. Basically they had to decrease the downstream valve opening when the LPG began to appear in the drain water. Then the valve could have been closed quickly at the end of drain work. Either they forgot to carry out this procedure or they could not close the second valve because it had also become stuck by freezing.

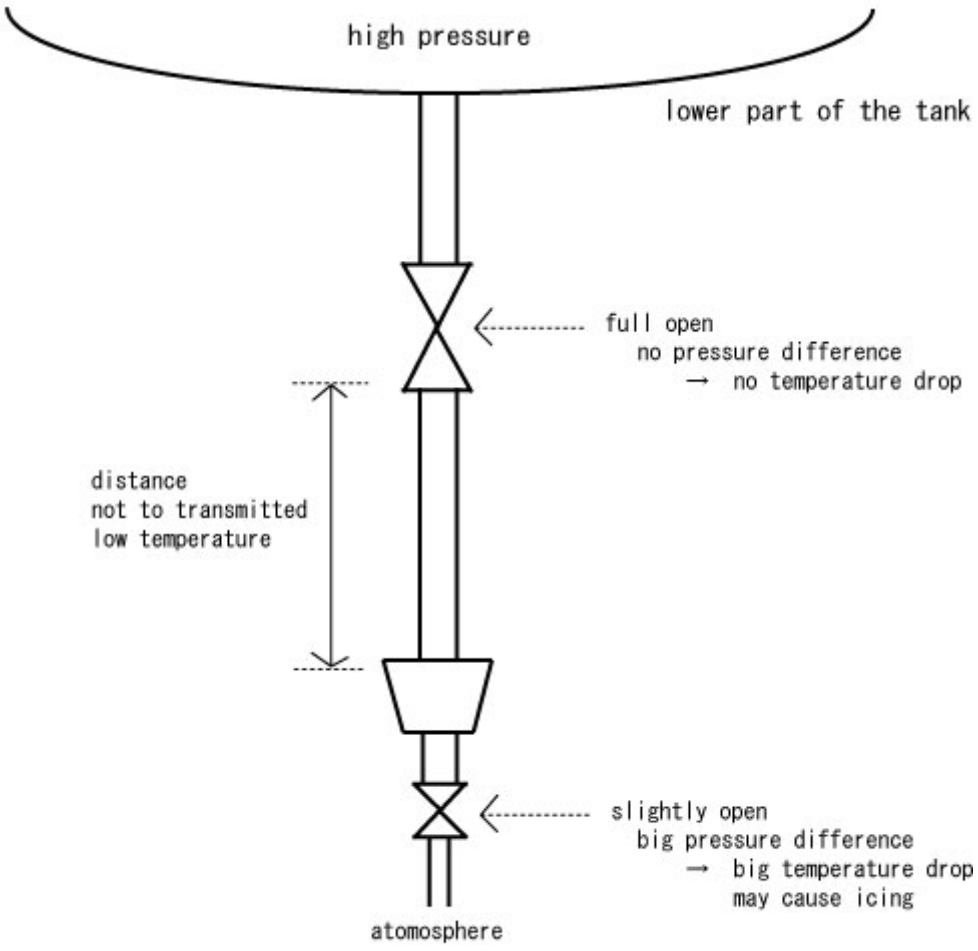


Fig.3 image of open drain valve

### 3.2. Cause of the ignition … (Refer to Fig.2)

It is presumed that the leaked LPG spread along the ground and was ignited by a car that was driving down the local road. The propane vapor was thought to have been ignited by a cigarette of the driver or the high temperature of the engine of the car that had just stopped.

It is not known why the traffic on the local road could not be stopped, though the traffic on the highway could be stopped. If there was enough time, and if a person who knew the roads in the area well had led the traffic restriction, it seems that the traffic on the local road would also have been stopped early.

Although the direct cause of the ignition is that the stopping of the traffic was delayed, the fundamental problem seems to be the layout of the area. The construction of the highway had been permitted with only a distance of slightly over 50m from the group of enormous LPG tanks. Moreover, from the photographs, it

appears that there was no dike around the LPG tanks. In this situation, when a large amount of LPG leaked, the LPG vapor flows along the ground to the highway. The main causes of the ignition are that the distance regulation was insufficient and there was no dike around the tanks.

Another possible cause of the ignition is the theory that a static electricity spark occurred when the LPG began spouting from the safety valve. However, if the ignition occurred at the initial stage of the leakage, a fire should have occurred, but an explosion should not have happened because enough LPG was not accumulated. Furthermore, after a large amount of leakage, the LPG might not ignite because the LPG concentration might be higher than the explosion limit. Therefore, it is considered that the possibility of the static electricity theory is low.

### 3.3. Cause of the first explosion

Before the accident it was assumed that the destruction and explosion of the LPG tank would not occur even if the tank was wreathed with fire, because the pressure relief valve (safety valve) would operate and decrease the tank pressure when the tank pressure rose by vaporization of the liquid LPG remaining in the tank due to tank heating. However, in fact the tank exploded, scattering many fragments of various sizes.

The explosion of the tank is explained by the BLEVE phenomenon, which has already been introduced (Refer to Fig.1). The accident at Feyzin is the first one that has been explained by the BLEVE phenomenon.

The water showering devices having at least a certain prescribed capacity are required for spherical and cylindrical LPG tanks in Japan at present. However, water showering for cooling from the top of the tank appeared not to have been executed at the tank, therefore, by heating the tank vapor phase, the BLEVE phenomenon happened and the explosion occurred.

### 3.4. Cause of the following explosion and fire

The nearby tank exploded as a result of the BLEVE phenomenon, and the fragments of the tank were scattered. The scattered fragments damaged the piping. However, only the piping damage might not have been enough to induce the following explosions of adjacent tanks. Some causes of explosions of the other tanks were being mentioned, and all of them were not confirmed, but they seem to have somewhat reasonable explanation in it.

First, the other tanks were cooled, but the cooling capacity for each tank may

have been insufficient. The BLEVE phenomenon is a natural result if the cooling capacity is insufficient. Second, the legs of the spherical tank were not made of a fireproof structure. The strength of the legs decreases rapidly when they are heated because they are made of iron. Eventually, the spherical tank falls down (Refer to Fig.4.). Third, the distance between tanks was so short that each tank could be affected by the adjacent tank. The distance between the centers of the tanks was only 27m according to the plans for the facility (Refer to Fig.2.). As the tank diameter was about 14m for the propane tanks and about 16m for the butane tanks, the distance between two propane tanks was 13m and between a propane tank and a butane tank was 12m. The minimum distance between LPG spherical tanks regulated at present in Japan is the same as the diameter of the larger tank, in this case, 16m, which seems insufficient. In any case, the distance between the tanks was even smaller than this Japanese regulation value. Considering the height of the flare, first 75m and finally 30m, the distance between the tanks might not have been enough.

## 4. Process of cause elucidation

As there are not any first hand reports of the accident or materials that show results of investigation into the actual conditions, it is not clear what kinds of method were used for the cause elucidation. Generally, the facts collected from interviews and the reports remained in the control room were lined up in order of time, and then they were examined with rational consideration. For this accident, the cause would have been elucidated using this general method.

## 5. Immediate action

The sounding of the alarm in the control room was the first notice of the accident, as shown in the “Course” section above. Although there is no clear description in the reports and other available materials, it is presumed that the gas leak detector operated. According to lecture materials that quoted from the Paris Match Magazine, a warning had been issued by the operation of the gas detector to all of the Feyzin districts. The moment the alarm rang, the first fire engine owned by the company turned out, and the company guards stopped the traffic on the highway. In other words, the following immediate actions were carried out: alarm, urgent fire brigade, and traffic regulation.

## 6. Countermeasure

There are many aspects that need to be considered in making countermeasures:

the cause of the leakage that triggered the accident, the cause of ignition, the occurrence of the BLEVE phenomenon, the spreading of the fire to the other tanks, and so on. The countermeasures made by the company itself and the countermeasures that made in relation to the local population are described below.

### 6.1. Countermeasure against freezing of valves

a) Generally, redundant sampling valves and drain valves are installed in series. In the tank involved in this accident, the double valve was already installed. In the LPG tank, doubling of the drain valves is a minimum requirement. The reason why the double valve is a necessary choice is that in the case of a single valve, there is a strong possibility that the valve main body will be cooled, hurting the closeout function of the valve by icing of the water in the air, generation of the hydrates, and other factors. Moreover, the distance between the two valves should be sufficiently long so that the low temperature of the second valve will not affect the first valve. The size of the second valve should be 1/2 inches or less for sampling and as small as possible for draining work. Fig.4 shows the composition of the draining and sampling valves of the tank where the accident occurred. It is desirable that a distance of 1m or more should be kept between valve A and valve B and between valve A and valve C. Also, the size of valve B should be 3/4 inches or less.

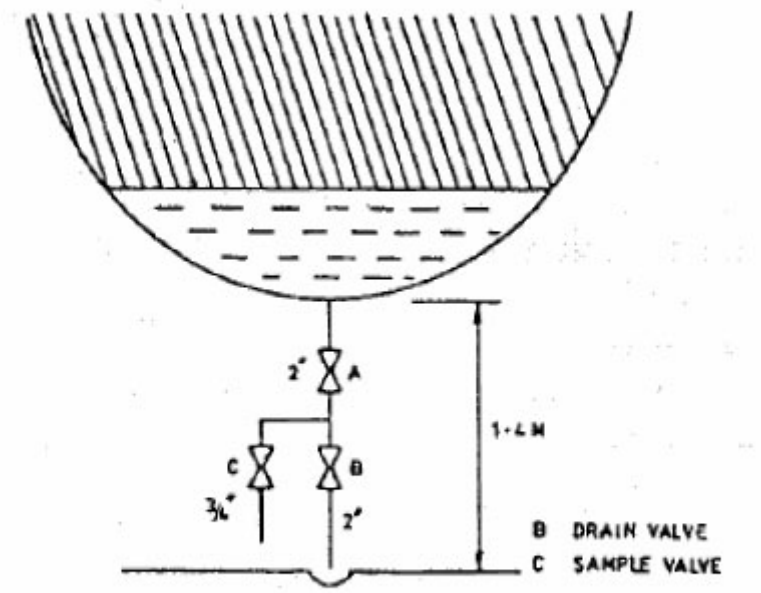


Fig.4 valve structure of the tank

b) Adequate education and training of the use of double valves is necessary. The operation described below has to be done completely: the first valve must be opened fully and flow adjustment must be done only with the second valve, because the temperature of the first valve must not to drop. The reason is shown in the "Cause" section. Also, a thorough monitoring of the draining work should be attempted.

### 6.2. Countermeasure for other facilities

In Japan, the following minimum standards are required by law.

a) Installation of a dike: LPG does not vaporize immediately, and even if it is vaporized, LPG spreads along the ground, because it is heavier than the air. A dike is effective for preventing the spread of LPG.

b) Facilities for water showering from the tank top: as a countermeasure against the BLEVE phenomenon, the tank wall should be cooled.

c) The fireproof structure of the legs: if the legs of the tank are made of iron, they will be damaged by heat.

d) Keeping the distance between tanks to prevent fires from spreading to and from adjacent tanks. In Japan, the diameter of the larger tank is required as the minimum distance between high pressure gas tanks at present. If it is possible, greater distance between tanks is desirable.

e) Installation of a gas detector for the detection of leakages.

f) The outlet of the safety valve: although Japanese regulations specify that the outlet of the safety valve should be "mounted at a safe position", in fact the outlet has often been mounted directly on the tank. This position cannot always be "safe".

g) The automatic cutoff for the excess flow rate (an excess flow valve): although there is no direct relationship to this accident and there is no regulation in Japan, it is desirable that a device should be installed that can automatically cut off the flow when the flow rate increases over the set rate from the tank bottom. This countermeasure has already been adopted in some countries, including Taiwan.

### 6.3. Countermeasure considered in relation to the society

The damage by the explosion and fire is enormous when a large amount of LPG leaks and spreads. The corporations that store and handle large amounts of LPG must consult with the local government for designing an adequate communication system that includes communication with the local government, notice to the local inhabitants, and instructions for how to restrict traffic in the case of an LPG leak.

The location of a large LPG storage facility must be studied carefully in relation to the environment and facilities surrounding the corporation because of the potential

damage resulting from the leakage of a large amount of LPG. In Japan, the distance regulation between high pressure gas treating facilities and the buildings for public use is carried out.

## 7. Knowledge

a) The handling of LPG may cause problems with freezing due to formation of ice from the moisture of the surrounding air and/or formation of hydrates when the LPG pressure is reduced to atmospheric pressure. Devices and methods that prevent the occurrence of low temperature hazards are important for operations such as draining work or sampling when the pressure may be reduced to atmospheric pressure. This is an important issue for all persons who are related to LPG processing and LPG handling, as well as to petroleum refining and petrochemicals.

b) Leaked LPG is a very dangerous material because the vapor density is heavier than air, the ignition point is low and it evaporates to form a combustible gas-air mixture easily, and the vapor is colorless and odorless. Sufficient attention and communication measures are necessary for storage and handling.

c) A special form of the explosion can occur in LPG tanks because of the BLEVE phenomenon. The danger of the explosion was increased in this accident by the fact that the stress that can be supported by the tank decreased when the part of the wall without a liquid was heated, because the tank was designed based on calculations of the stress that can be supported by the iron wall at ambient temperature. A shower system with sufficient capacity for spraying cooling water on the tank fire from the tank top is a necessary measure. Although the tank internal pressure is given by the equilibrium pressure of the liquid at the temperature in the tank, the temperature in the vapor phase may be independently determined. It is an example of losing an equilibrium relation in the case of localized heating.

## 8. Influence of failure

Although there are various different reports, it appears that 18 to 81 persons died and about 80 to 130 persons were injured, including the members of the fire-fighting brigade. The physical damage included five LPG tanks, many atmospheric tanks containing crude oil and jet fuel, and so on. The Feyzin Refinery suffered extensive damage. Reports that mentioned the damage to the neighborhood area are not found. One report estimates the total amount of damage to be about 18 million US dollars in dollar values at the time of the accident, or 70 million US dollars in 1990 dollar values. However, considering the actual amount of damage to the neighborhood,

the cost of the reconstruction of the factory, the non-operation losses, and so on, the monetary damage must be much larger.

Fig. 5 the accident tank fell down

Fig. 6 Photo of the tank yard at fire

## 9. On the side

There are many examples of accidents involving LPG. The explosion of the Pemex Co. LPG terminal in Mexico City, which occurred in November 1984, destroyed six large spherical tanks, 48 small horizontal cylindrical tanks, and much of the nearby residential area, and over 500 persons died, over 4,000 persons were injured, and several tens of thousands of houses were severely damaged. The cause of that accident was not described clearly. The site limits might not be clear and apparently LPG was often stolen from the facility, and thus a large LPG leakage seemed to have occurred. The LPG spread along the ground in the same way as in the Feyzin accident and ignited somewhere else, causing the terrible disaster. In Japan, there also are many reports of awful disasters due to neglect of danger at LPG filling stations and other LPG handling facilities.

A great number of reports and explanations of this accident exist, and contents of each report are different one others, so the facts are not so clear. In this report, it is assumed that propane leaked from an un-closed valve due to hydrate formation during draining work, and the vapor was ignited by a car traveling on the local road near the refinery.

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