Tank Explosion at the LP Gas Filling Station

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(Summary)

In November 1964, there was a great tank explosion disaster that resulted in three deaths and 61 injuries at an LP gas filling station in Osaka. At the filling station, LP gas leaked and was ignited during an attempt to fill containers with LP gas using the pump from a tank truck. Heated by the flames of the fire, the LP gas containers and the 10 ton horizontal tank at the station exploded one after another. With this event as a turning point, nationwide training and guidance were provided to the management and working staff at LP gas filling stations across the country in order to establish an assured safety management system and ensure the proper maintenance and checks of equipment.

1. Event

At the LP (Liquefied Petroleum) gas filling station, an attempt was made to fill a 10 kg container and a 50 kg container with LP gas using the pump of the tank truck instead of the compressor and pump of the station, which were out of order, but this attempt failed and was abandoned. (See Figs 1 and 2.)

About 30 minutes after the attempt was suspended, white fumes suddenly spouted out with a hiss from somewhere in the line connecting the tank truck and the containers and completely filled the area. There then came, and the explosion occurred after that. Heated by the resulting flames, the LP gas containers and the horizontal tank burst one after other, resulting in a catastrophic explosion disaster with three deaths and 61 minor and serious injuries. According to the investigation carried out after the accident, LP gas was presumed to have blown out due to either the rupture of a deteriorated hose or the breakage of some coupling caused by the movement of the tank truck.

The figure below shows the results of a fault tree analysis.

Fig. 3: Fault tree diagram with a focus on mode, mechanism, and process of fracture

LP gas blew out so rapidly that it took only about 20 seconds to fill the area and flow over the concrete-block wall that surrounded the site of the filling station. It is estimated that the total volume of white fumes and the rate at which the gas blew out immediately before the explosion were more than 600 m3 and about 360 liters per minute, respectively.

The horizontal tank ruptured due to a ductile fracture in the longitudinal direction of the barrel plate. The barrel plate (60 kg class high strength steel) was heated to the recrystallization temperature, and its pressure strength at 650°C was 20.7 kg/cm^2. The operating pressure of the safety valve was 29.8 kg/cm^2, which was higher than the pressure strength of the barrel plate. This suggests that a rupture hole had formed on the barrel plate due to a longitudinal ductile fracture before the safety valve could operate.

The inner surface of the burst horizontal tank left a clear mark of discoloration that showed the boundary surface of the gas liquid. From this fact, it is presumed that about six tons of liquid was contained in the horizontal tank immediately before the explosion. Furthermore, the safety valve had been operating normally until just before the explosion. These facts demonstrate that the LP gas in the horizontal tank was not above the critical temperature. As a result of the investigation, the explosion was believed to occur as follows. A large volume of LP gas was released from a rupture hole that had formed on the barrel plate due to a rise in the inner pressure, and so the inner pressure dropped suddenly. A quick drop in the inner pressure disturbs the gas-liquid equilibrium, causing the liquid to boil intensely in an overheated condition. As a consequence, a large volume of gas evaporated instantaneously, resulting in a powerful impact pressure exerted on the tank. This series of events -- known as a steam explosion -- caused the entire horizontal tank to break into pieces starting from the rupture hole formed on the barrel plate.

The figure below shows the results of an event tree analysis.

Fig. 5: Event tree diagram of horizontal tank explosion

2. Course

At the LP gas filling station, there was one 10 ton horizontal tank unit, from which LP gas was filled into 10 kg and 50 kg containers. The monthly sales at the filling station was about 100 tons, and the horizontal tank was refilled with LP gas from two 4.8 ton tank trucks every three days.

On the date of the accident, the manager of the filling station made a phone call to cancel the dispatch of the tank truck that had been reserved because there still was a sufficient volume of LP gas left in the tank, but the tank truck had already left at that time. In the meantime, the staff members of the filling station were transferring LP gas into containers without using the pump because the pump and the compressor were out of order.

The tank truck arrived at the station in the afternoon, but the driver of the truck was asked to wait until enough of the LP gas in the horizontal tank was used so that the gas contained in the tank was at a level low enough to accept the LP gas from the tank truck. While watching the inefficient operation of transferring LP gas manually, the driver suggested filling the gas into the containers using the pump of the tank truck. He connected the pressure equalizing line between the horizontal tank and the tank truck and tried operating the pump. However, the plan did not work and the idea was abandoned.

About 30 minutes after the driver's plan was abandoned, white fumes suddenly spouted out with a hissing sound and completely filling the area impairing visibility. About 20 seconds after the gas blowout had started the gas ignited. Heated by the resulting flames, the LP gas containers ruptured, and gas blew out intermittently from the safety valve of the horizontal tank. About 18 minutes after ignition, the horizontal tank exploded, and its broken pieces scattered into the surrounding area.

The post-accident investigation revealed no trace of any fracture from the main body of the tank truck through the pump to the hose joint and that the horizontal tank was not connected to the tank truck and the filling zone. (See Fig. 4.) Therefore, the origin of the blowout of the large amount of LP gas must have been somewhere in the connection hose, including the couplings, between the tank truck and the horizontal tank. A deteriorated LP gas hose could rupture even within the operating pressure range, although its normal burst pressure is 90 kg/cm^2.

In addition, the tank truck had moved back 2 m from its original position to a position where the hose did not fully reach the reception port of the tank. The roll-off section of the thread of the coupling on the liquid feed line was stripped, and the coupling on the pressure equalizing line was removed with its thread stripped. The roll-off section of the thread was stripped easily when the tank truck moved, since it was only 2 mm in thickness and about 0.8 tons in bending strength.

3. Cause

(1) Unfamiliar operation by inexperienced staff

The root cause of the LP gas blowout was the attempted filling operation using the pump of the tank truck. Although this is not an uncommon operation, it was the first attempt at this station and was done when the operation supervisor was not present.

Additionally, no wheel stoppers were used to prevent the tank truck from moving accidentally. The tank truck was customarily parked with its rear wheels on the sleeper wood in order to balance itself on the inclined surface of the site. Furthermore, the pressurized hose was left connected to the pump even after the attempt was abandoned. All of these observations suggest that the staff at the filling station lacked sufficient safety awareness.

(2) Limited space

The filling station had only a very limited space and was crowded with individual installations. As a result, although the firefighting crews rushed to the site only three minutes after the initial ignition, the LP gas containers burst one after another and the horizontal tank exploded while the firefighting crews were extinguishing the flames from the containers. Also, because of the close proximity of the horizontal tank and the firewall combined with the short height of the firewall, flames were concentrated intensely on the upper half of the horizontal tank, thus causing the tank to burst.

4. Immediate Action

If a fire occurs at a gas filling station, highest priority should be given to stopping the blowout and leakage of gas even at the early stage of the fire. In general, the blowout or leakage of gas can be stopped by accessing the stop valve or other control values from a safe direction, because the direction and the scale of a fire usually remains constant for a while after an initial explosion has occurred.

However, if LP gas blows out in a liquid state as in this case, the concentration of LP gas could become higher than the explosion limit in the range of white fumes that result from evaporation and cooling. Therefore, one should avoid entering the area containing white fumes except when it is confirmed that there is no possibility of ignition.

5. Countermeasure

With this event as a turning point, countermeasures were implemented, including regulations to:

(1) Provide sufficient space or install a barrier between individual equipment;

(2) Install a sprinkler system and a level gauge to the LP gas tank;
(3) Apply improvements to the tank truck, including the inspection of excess flow valves, the protection of protruded parts, and the standardization of hose and coupling structures/dimensions;
(4) Encourage the drivers of tank trucks to pull the handbrake and apply wheel stoppers when parking a tank truck;
(5) Improve the management's awareness of autonomous safety;
(6) Provide practical training to the working staff at the gas filling station (including the drivers of tank trucks); and
(7) Promote a qualitative improvement of the equipment at the gas filling station by ensuring that every staff member is aware of and adheres to the autonomous safety standards.

6. Knowledge

○ Build a high level of safety awareness

This accident could have been prevented if the management and the staff had maintained a sufficient level of safety awareness and had performed proper maintenance on a regular basis. The management should be well aware of the potential risks of what they are handling and take all possible safety measures at all times. (See Fig. 6.)

○ Potential risks of an LP gas tank in the case of a fire

If heated by the flames of a fire, an LP gas tank could possibly burst due to an increase in the inner pressure of the tank even within the range of the operating pressure of the safety valve. Needless to say, LP gas would leak even if the safety valve operates correctly. Therefore, it is very difficult to address this problem technically.

7. Background

At the time of the accident, the LP gas business was developing at a rapid pace, and the layouts and scales of filling stations were changing year by year. In the early days of the LP gas industry, the staff members at the gas filling stations were still inexperienced, and the safety management system there was lacking.

8. Sequel

With this event as a turning point, nationwide training and guidance were provided to the management and working staff at filling stations across the country in order to establish an assured safety management system and ensure the proper maintenance and checks of equipment.

9. Social Impact

The interested parties in the LP gas industry were greatly shocked by the fact that an LP gas tank had exploded even if the safety valve operated. This event disproved the general assumption that LP gas tanks were free from the risks of explosion in a general fire.

10. Information Source

(1) Research Report on the Accident and Countermeasures at LP Gas Filling Station: Extra Issue of High Pressure Gas Safety Institute of Japan Report, Jan. 1965.

11. Primary Scenario

01. Organizational Problems
02. Poor Management
03. Poor Maintenance
04. Compressor / Pump Failure
05. Misjudgment
06. Narrow Outlook
07. Insufficient Experience / Skills
08. Non-regular Operation
09. Change in Operation
10. Filling LP Gas with the Pump of Tank Truck
11. Leaving Hoses as Connected
12. Movement
13. Careless Movement
14. Movement of Tank Truck
15. Failure
16. Fracture / Damage
17. Chipping of Coupling
18. Damage
19. External Damage
20. Leakage
21. Fire
22. Failure
23. Degradation
24. Drop in High-temperature Strength of Horizontal Tank
25. Failure
26. Fracture / Damage
27. Burst of Horizontal Tank
28. Release of LP Gas
29. Bad Event
30. Thermo-Fluid Phenomenon
31. Thermal Phenomenon
32. Inner Pressure Drop
33. Secondary Damage

34. External Damage
35. Steam Explosion
36. Burst of Horizontal Tank

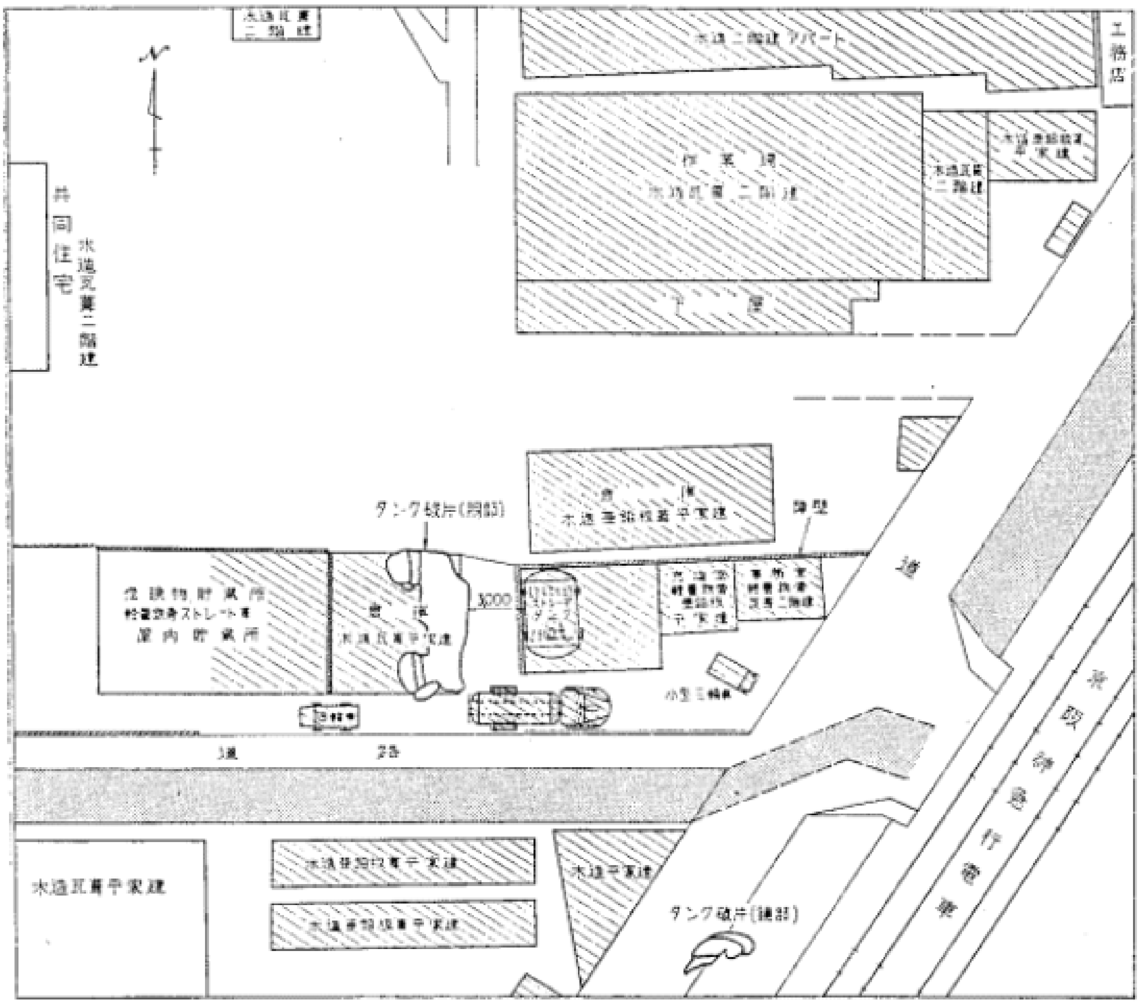

Fig. 1 The scene of an accident.

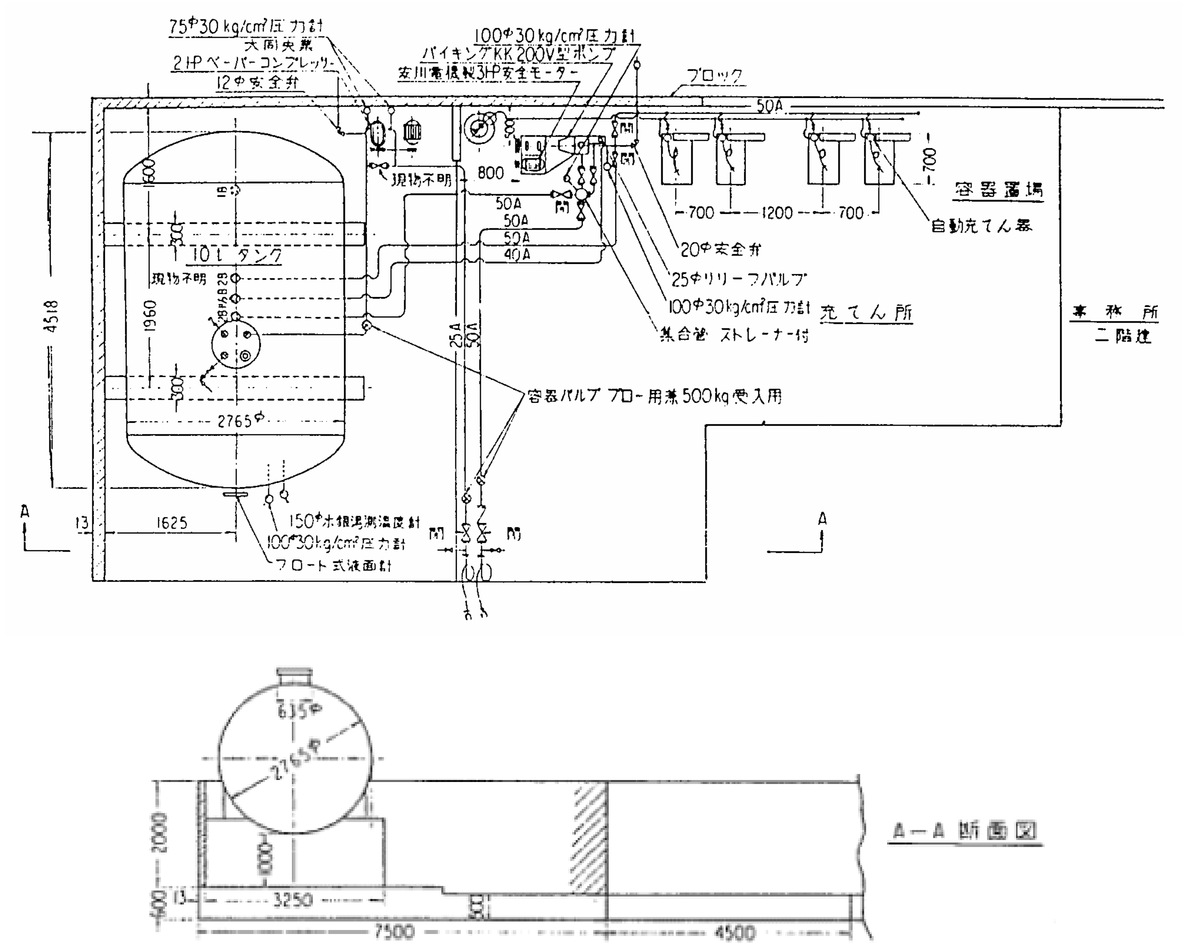

Fig. 2　Arrangement machinery.

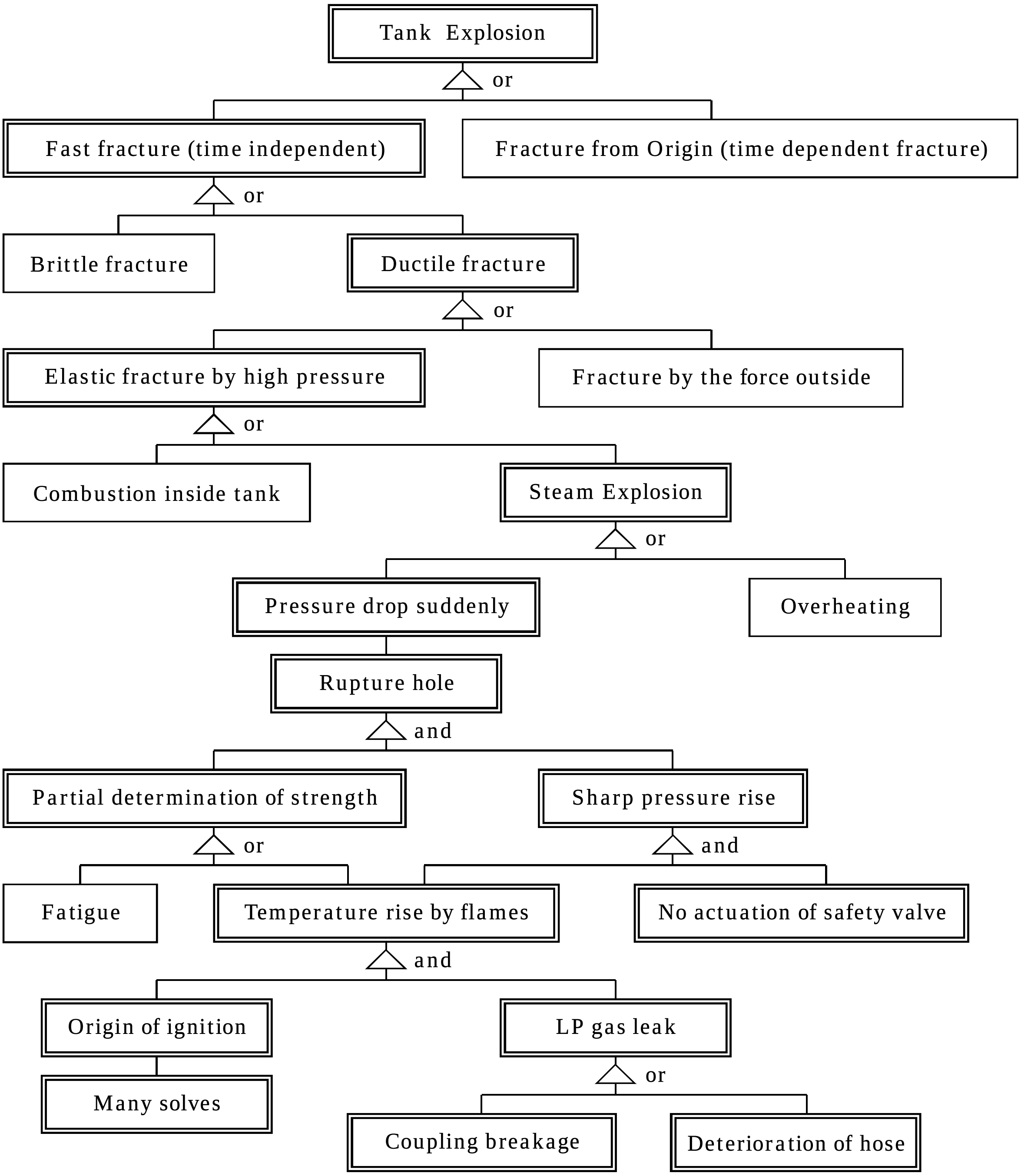

Fig. 3 Fault tree diagram with a focus on mode, mechanism, and process of fracture.

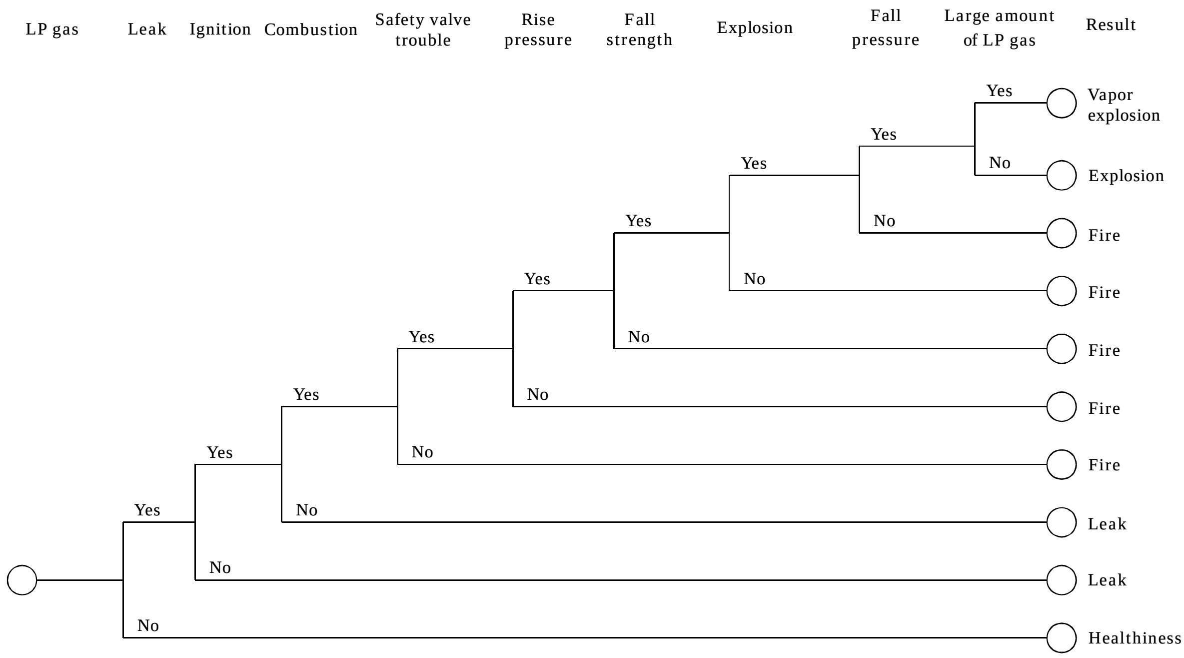

Fig. 4 Event tree diagram of horizontal tank explosion.