Explosion of Liquefied Nitrogen Storage Tank by Closing Shutoff Valve for Safety Valve

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(Summary)

In a food factory located along a national road, the liquefied nitrogen storage tank for the cold evaporator (CE) exploded at a mid-night, causing the destruction of the upper half of the factory as well as some extent of damage to other factories and structures in a circle with radius of 400m. The shutoff valve for the safety valve had been closed manually, causing the tank to close totally. The pressure of the tank increased gradually as a result of heat penetration, leading to the explosion which occurred more than one month later.

1. Component

A schematic diagram of the liquefied nitrogen storage tank (CE, cold evaporator) is shown in Figure 1. The cold evaporator is an apparatus which sends pressurized gases, such as oxygen, nitrogen, argon, carbonic acid gas, etc., to users, after evaporating the stocked super cold gases by using the pressurizing evaporator, the sending gas evaporator, and other attached equipments. "Super high temperature" and "extremely cold temperature" are used generally as terms describing extreme temperature, but in this field, "super cold" is used instead of "extremely cold".

A double shell, vacuum insulated tank maintains thermal insulation by evacuating the insulator chamber packed with pearlite between inner vessel wall, made of stainless steel, and outer vessel wall, made of carbon steel. The degree of thermal insulation, therefore, depends on the degree of vacuum.

2. Event

In a food factory located along a national road, a liquefied nitrogen storage tank exploded and dispersed at mid-night, causing the destruction of the upper half of the factory as well as damaging other factories and structures partially, including the outer walls, window glass, and shutters of 25 buildings, 39 parked vehicles consisting of busses, trucks and cars, and electric poles in a circle with radius of 400m (Figure 2~4). The tank was a vertical type, double shell, vacuum insulating vessel (model CE-7500), and it is shown in Figure 1, with its attachments. Exploded circumstances of the inner and outer vessels are shown in Figure 5 and 6, respectively. The piece of the vessel that flew the furthest was the top dish plate of the outer vessel, 1.5m in diameter and 8mm in thickness that reached a distance of 350m. The insulator composed of pearlite scattered over circular area with a radius of 100 m. The appearance of the top dish plate is shown in Figure 7. The direct cost of the damage was estimated to be about 440 million yen.

3. Course

The storage tank was fabricated by Nissan Kogyo Co. in September 1973, and it was set up in the Ishikari Factory of Suzuki Sogo Food Co. in September 1988. After being set up, the first, second, and third annual inspections were conducted by Hokusan Engineering Co. each September in 1989, 1990, and 1991, respectively. Daily inspections at start up, shut down, etc. by Suzuki Sogo Food Co. were not conducted at all, nor was any safety training conducted.

The tank was charged with nitrogen gas on June 26th, 1992, and the gas was used on June 27th and 28th. After that, a lorry of Tomakomai Distribution Center, Hokusan Co. charged the tank with 2000m3 of gas equivalent to 2800m3 when converted under standard atmospheric pressure and temperature. The tank had not been used for 61 days when the accident occurred.

The Ministry for International Trade and Industry organized the Research Committee on Liquefied Nitrogen Storage Tank Explosion Accident, chaired by Prof. H. Kobayashi, in the High Pressure Institute of Japan on September 1st, 1992, because of the importance of the accident in society. The total number of the liquefied nitrogen storage tanks in all of Japan had reached 9000.

4. Cause

The results of analyzing the cause of the accident are as follows;

(1) The exact time of the accident was not determined, but the safety valve with spring had been actuated or the shutoff valve for the safety valve had been closed manually without actuating some time after the last annual inspection in September 1991. After that, even though the time was also not determined strictly, the rupture plate was estimated to explode so as to close the shutoff valve manually. The stock tank, therefore, became totally closed.

(2) The pressure of the liquefied nitrogen in the stock tank increased gradually through the penetration of external heat under the completely closed condition, eventually exceeding the rupture pressure of the inner vessel (about 7 MPa). The period of time required reach this condition was estimated to be between 50 and 80 days.

(3) Because of the increased pressure, the outer vessel exploded following the explosion of the inner vessel, causing the dispersion of pieces of the vessel including the attachments. The rupture pressure of the outer vessel was also about 7 MPa, estimated from the flying distance of the broken pieces of the inner and outer vessels. The fault tree diagram showing the fracture morphology, mechanism, and process is shown in Figure 8. The event-tree diagram is also shown in Figure 9.

5. Immediate Action

Liquefied inert gas (nitrogen, argon, carbonic acid, etc.) storage tanks are widely used for various purposes such as freezing, gas replacement. They regarded as relatively safe equipments so that some of the regulations are relaxed compared with other production equipments. Liquefied inert gas storage tank can, however, cause serious problems under the wrong operating conditions. All persons who are concerned with such equipment should, therefore, change the conventional recognitions that the inert gas is always safe, and adopt the safest and wisest measures for preserving maintenance.

6. Countermeasure

(1) Increasing the awareness of the importance of safety maintenance

Closing both the spring type safety valve and the shutoff valve was conducted by employees of the factory who do not have enough awareness of the importance of safety maintenance, and who did not have the basic knowledge that the shutoff valve for the safety valve must always be kept open. There was also the serious problem that the managers of the factory lacked sufficient awareness of the importance of safety maintenance so that they did not order daily inspections by the employees, and they also entrusted the annual shutdown maintenance to some outside maintenance companies.

(2) Improving manuals and arrangement of valves

The manuals for operation of safety valves and for communications with gas suppliers were incomplete. The arrangement of valves was also complicated and difficult to operate.

(3) Support by gas suppliers

Gas suppliers should support user companies in achieving items (1) and (2) mentioned above.

7. Knowledge

The basic knowledge that the shutoff valve for the safety valve must always be kept open should be reaffirmed. The common sense notion in society that the shutoff valve of gas in homes must be kept closed and that the electric breaker must be turned off before leaving for long time, is not appropriate for factories. Those who do have the basic knowledge about safety valves have the misunderstanding that a closed shutoff valve is safer than open one. Cold evaporators are used so widely in society recently that the affirmation of this basic knowledge must be reconsidered.

8. Social Impact

The following items were mentioned as being strong influences to society,

(1) The distance over which pieces of the tank were dispersed was large compared to that of past incidents.
(2) The same type of cold evaporator is used in about 9000 sites all over Japan.
(3) The same type of cold evaporator for liquefied oxygen is used for medical purpose in hospitals.
(4) Other evaporators of same type have a similar possibility to cause accidents.
(5) Cold evaporators belong to a class of equipment that can be used with only notice. This class of equipment is used by the second class manufacturers, who have no legal obligations of safety maintenance and periodical voluntary inspections.

9. Information Source

(1) Report of Research Committee for Accident of Liquefied Nitrogen Storage Tank, The High Pressure Gas Safety Institute of Japan, August, 1993.
(2) Hideo Kobayashi, Takao Nagasaki, Hideo Ohtani, Yuji Wada, Teruo Yoshioka, and Akio Hori: Analysis for accident of liquefied Nitrogen Storage Tank (CE), Journal of The Japan Society of Mechanical Engineers (A Edition), **60**-572(1994), 1100-1107.

10. Primary Scenario

01. Ignorance
02. Insufficient Knowledge
03. Too Presumptive
04. Misjudgment
05. Narrow Outlook
06. Inexperienced/Not habituated
07. Regular Operation
08. Erroneous Operation
09. Incorrect Operation
10. Close the Shutoff Valve for Safety Valve
11. Usage
12. Operation/Use
13. Use of Equipments/Materials
14. Liquefied Nitrogen Storage Tank
15. Bad Event
16. Thermo-Fluid Event
17. Thermal Event
18. Penetrated Heat
19. Pressure Increase of Liquefied Nitrogen
20. Failure
21. Large-Scale Damage
22. Rupture
23. Secondary Damage
24. External Damage
25. Scatter of Broken Pieces

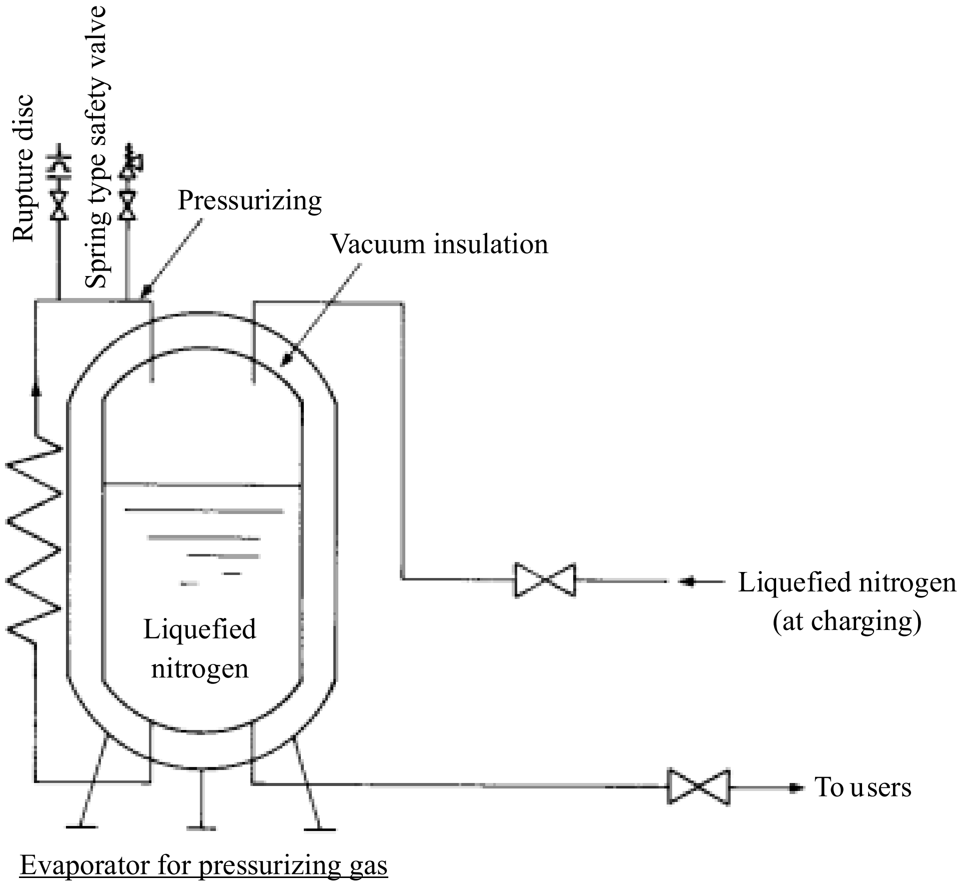

Fig. 1 Schematic diagram of storage tank.

Fig. 2   Appearance of damage (Part 1).

Fig. 3   Appearance of damage (Part 2).

Fig. 4　Appearance of damage (Part 3).

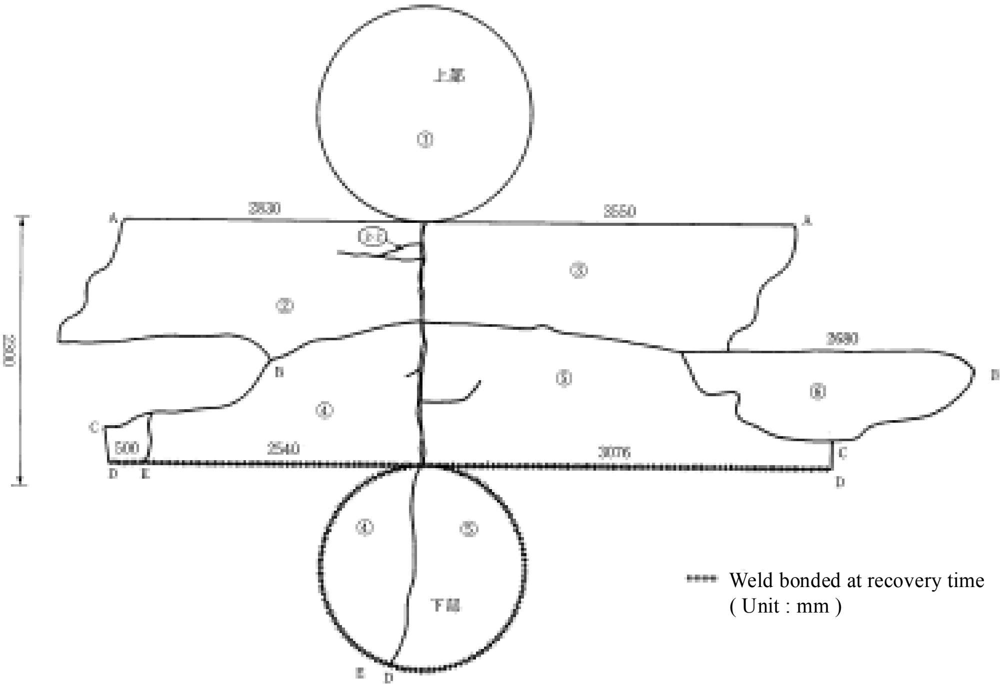

Fig. 5 Exploded circumstances of inner vessel (Stainless steel).

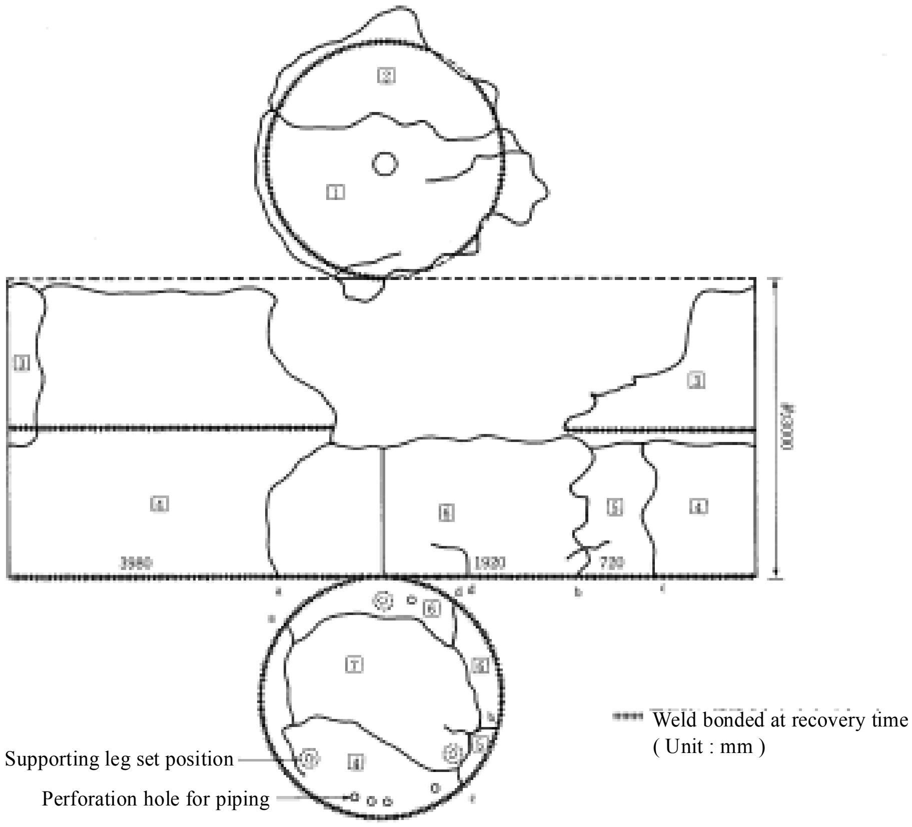

Fig. 6 Exploded circumstances of outer vessel (Carbon steel).

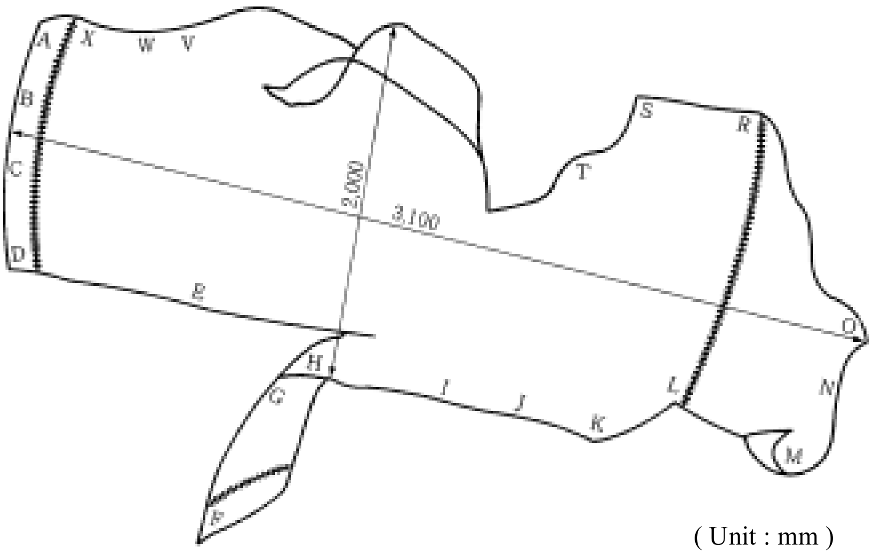

Fig. 7 Crushed piece of top dish plate of outer vessel.

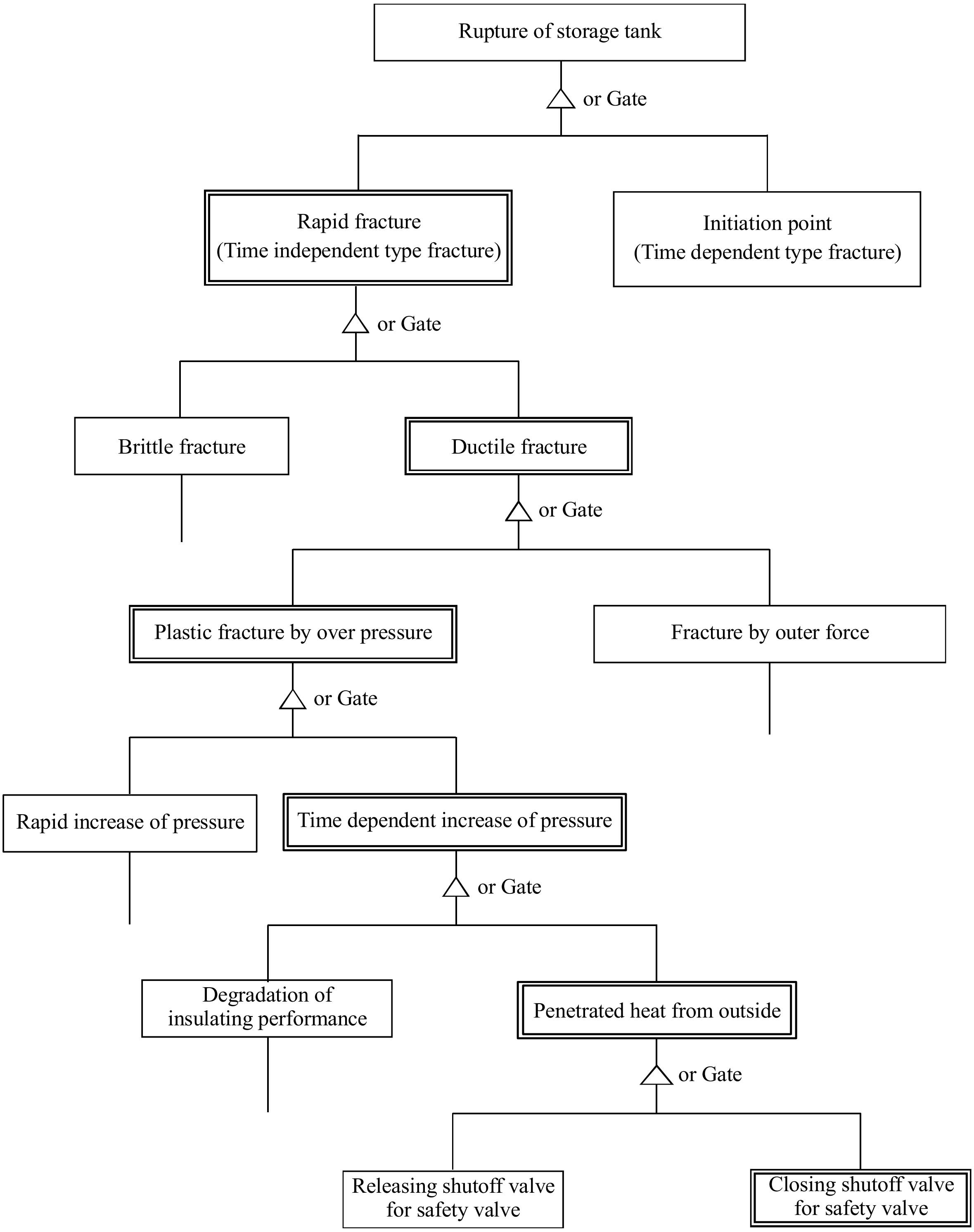

Fig. 8 Fault tree diagram noticing morphology, mechanism, and process of fracture.

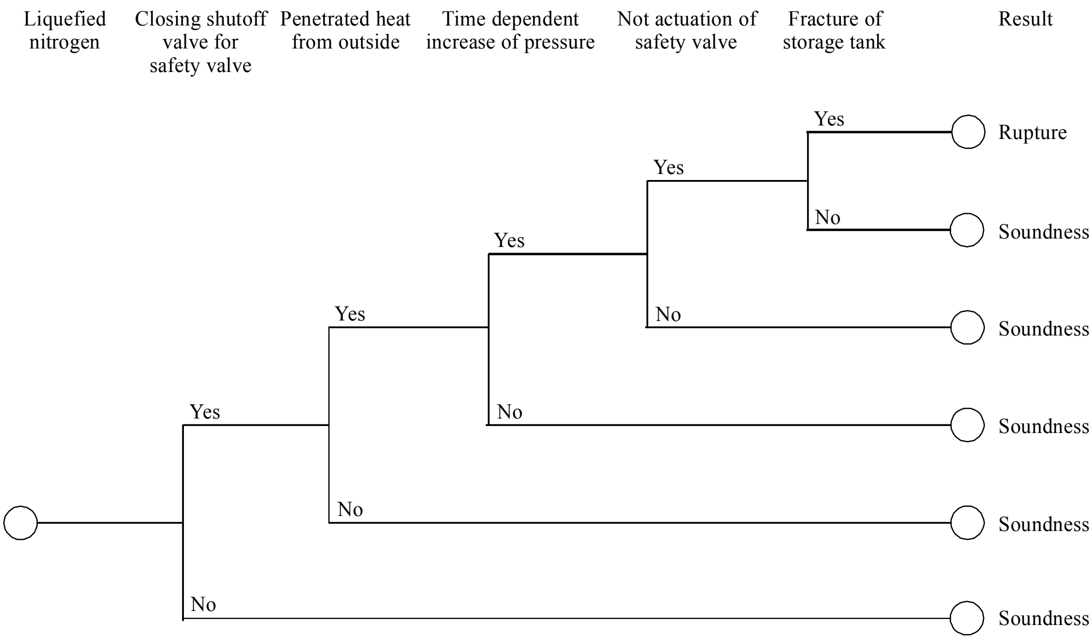

Fig. 9　Event-tree diagram for explosion of storage tank.