Poison Gas Leakage from Chemical Plant in Bhopal, India

【December 2nd, 1984　Bhopal, India.】

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From mid night of December 2nd, 1984 to the dawn of the 3rd, Bhopal, the state capital of Madhya Pradesh in central Indi a, was conta minated with toxic gas. An enormous disaster resulted with over 2000 persons dying on the spot and 200,000 to 300,000 per sons injured. The final number of fatalities was reported to be 14,41 0 persons. Th e toxi c gas was methyl isocyanate (MIC) that is used as a pesticide raw material, an d it leaked from th e st orage tanks of Union C arbide Ind ia Co. (UC IL) in the suburbs of Bhopal. MIC is used as a raw material for organic s olvents and s oil fumigants, etc. MIC is much more toxic th an even the famous phosgen e gas, and the average acc eptable conc entration of work envir onment p er eight hou rs in the USA is 0.02 ppm, which is 1/500 of the 10ppm limit that is allowed for cyanogen compounds.

The leakage accident began with the contamination of the water in the MIC storage tank. An abnormal r eaction was caused , the p ressure rose, and MIC le aked from t he storage tan k. Safety eq uipment th at had been left in und esirable c ondition d id not operate, and MIC leaked outside of the factory. The leaked MIC spread to the city along the ground by the northwest wind, and the citizens were exposed to the gas while t hey were sleeping. As the accident occurred at midnight, proper public information was not made availa ble, and the citizens were unabl e t o take refug e, causing t he damage to spread. The local p eople had not been infor med that d angerous M IC was being manufactured and stored in the factory. Furthermore, n either the administrative authorities nor the medical personnel of the city had knowledge about t he cure for t he MIC p oison; this fact may also h ave been a factor lead ing to the enormity of the damage.

When th e background of this accident is co nsidered, t he relation between t he lifecycle of manufactured go ods an d the management poli cy of the enterprise can be noticed. UC IL was an I ndian subsidiary of Union Carbide and Carbon (UCC) in the USA. UCC possessed over 50% of the capital o f UCIL, and UCIL m anufactured MIC and its final product, pesticide, using U CC technology. The MIC plant was constructed in 1977. H owever, around the time of accident, a cheaper and safer pesticide manufactured by a different system went on the market, and the business of UCIL was

in a bad condition. At the end of the fiscal year in 1982, the profit was zero, and it was forecasted that there would be a four million US dollar deficit in 1984. Therefore, the management of the factory was rationalized, safety education was seldom carried out, and safety of the facilities and operation was disregarded, and problems occurred often. This chain of events is considered to have caused the catastrophe. This disaster was not only the problem of the local subsidiary that was operating the plant, but also the problem of the responsibility of the parent company.

1. Event

From midnight of December 2nd, 1984 to the dawn of the 3rd, the deadly poisonous MIC gas leaked from the storage tank. MIC, which was an intermediate in pesticide manufacture, was stored in three storage tanks of the pesticide factory in UCIL Co. at Bhopal in central India. MIC evaporated as a result of an abnormal reaction. The northwest wind was blowing on that night, and the temperature was low, so the leaked gas spread silently to the southeast over the ground to cover an area of about 40 km^2 in the city. Because the accident occurred at midnight, the citizens were not able to take refuge. The number of victims was at least 200,000 persons, which was over one quarter of Bhopal's population of 800,000, and according to other estimates, the number of victims was as much as 300,000 persons. The number of instant deaths exceeded 2000, and the final number of fatalities was 14,410 persons.

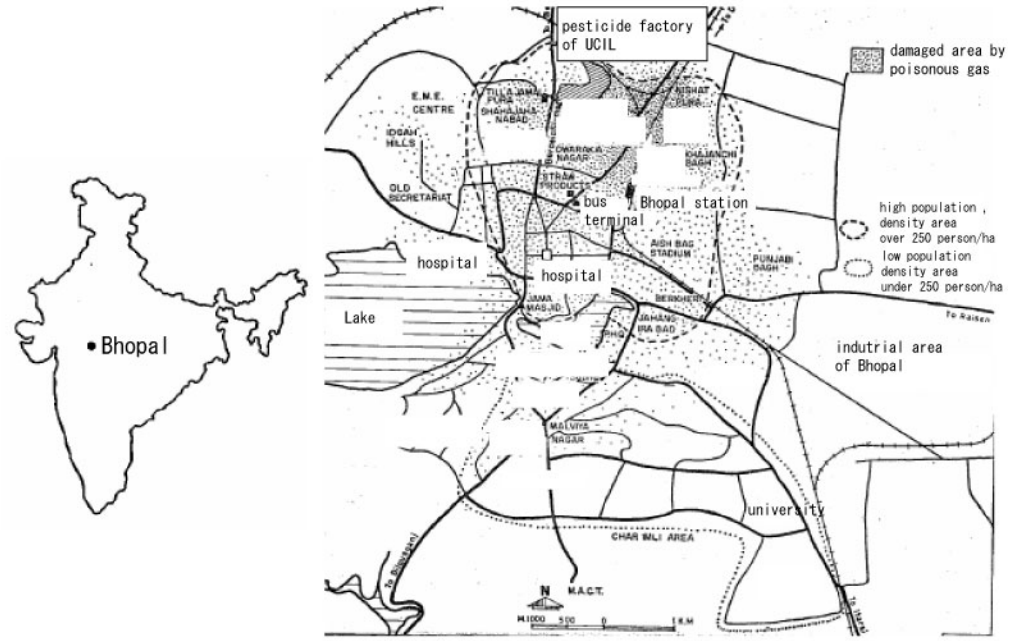

Fig. 1 Spread of the damage

The manufacturing plant had stopped operation a few days before the day when the accident occurred. For some days before the stopping, the off-specification product, which contained high concentration chloroform, was rundown into one tank of the three storage tanks. From the tank in which the off-specification product was stored, MIC vapor was generated by a work error, and MIC gas leaked from the tank because safety devices did not operated.

2. Course

The manufacturing plant had stopped operating since October 23rd. However, in the operation from 18th to 22nd, MIC containing 12 to 16% chloroform, which exceeded the specified maximum content of 5%, was rundown, and that MIC was stored in a storage tank where the accident occurred.

MIC vapor was generated due to an increase in temperature and pressure of the liquid, which was caused by an abnormal reaction in the tank. In the afternoon of the day of the accident, the water washing work of the vent piping of the tank was carried out. In the safety manual, the operation of "inserting a blind plate" was specified, but the blind plate was not inserted. The water used for washing entered the tank by seat leakage from a valve or new piping that was mounted just before the accident. The operators discovered a rise in the tank pressure at 23:00 on the same day, and they tried to take some measures but were not able to reduce the pressure. Next, they noticed MIC vapor leakage at 23:30, but they could not do anything to stop it. At 00:45 on the next day, the leakage quantity of MIC increased, and the leaked gas broke some equipment and then spread in the factory. The plant manager who was called reached the factory at 02:30, and then he notified the police. This was the only communication with anyone outside of the factory. At 03:30, the leaked vapor diffused outside the factory.

The management conditions of the MIC tanks are described below. For management of MIC, which is very dangerous and has a low boiling point, three kinds of safety devices had been prepared: a refrigeration unit for keeping the tank temperature at 0℃ or lower because of the low boiling point of MIC, a scrubber for absorbing MIC vapor by alkali, and a flare stack to burn leaked gas. However, the refrigeration unit was stopped from July. As the temperature alarm of the tank was not operating, the alarm did not ring when the temperature rose over 5℃. The scrubber was not effective because the circulation pump of the absorber had been stopped from October 22nd. The flare stack had also been stopped for piping work. Therefore, the generated MIC gas diffused first outside of the plant and then outside of the factory.

As the wind direction that night was from the northwest, the leaked gas spread towards the city zone where the population was most dense. A large amount of human damage was an inevitable result of high toxicity of MIC, of the large leakage quantity 35 tons in total, of the time of the leakage that was midnight, and of a lack of publicity activities and rescue operations.

The history of UCIL Co. is described below for reference.

The company was established as a dry cell manufacturing company in 1934, and the firm name was changed to UCC India in 1959. The compounding of insecticide was started in 1969, and the manufacturing of insecticide based on MIC was started in 1977. The MIC manufacturing plant where the disaster occurred was constructed in 1980. The disaster occurred in 1984, and the Bhopal factory was closed thereafter.

3. Cause

The causal chain of events leading to the leakage of MIC vapor is considered as follows. The off-specification product that contained much more chloroform than the specification was distilled into a storage tank for a few days before the plant stooped operation. A large amount of water was contaminated in the tank. Hydrochloric acid was generated from the high temperature reaction of chloroform and water. Hydrochloric acid corroded stainless steel of the tank material, dissolving iron. With the iron as a catalyst, a series of abnormal reactions were caused, which led to leakage of MIC vapor. The series of abnormal reactions is shown below. MIC vapor leaked from a safety valve, and a pressure relief valve due to a pressure rise caused by carbon dioxide formation and MIC vaporization.

MIC reacts with water to form carbon dioxide and methylamine with the generation of heat. In addition, due to the rise in temperature and the catalytic effect of iron, trimers of MIC were formed with a large heat generation of 325kcal/kg-MIC. The temperature became high due to the reaction, causing a runaway reaction to occur. The reactions from the generation of hydrochloric acid to trimerization of MIC had been known.

The underlying cause of the accident was the production of off-specification product during on-stream operation. A little production of off-specification product might be inevitable, and it is not an important matter. However, the off-specification operation continued for four days. They had more than three years of operation experience, so the long off-specification operation seems abnormal. Moreover, the contents of the off-specification were a large amount of chloroform, which, when combined with water contamination, is very dangerous. However, they did not seem to take any particular

care regarding water contamination.

The direct trigger of the accident is water contamination in the tank, and the causes appear to be a violation of work instruction in the water washing operation and leakage of the valve. The manager had ordered the work, but he arrived at his post just before the accident, and he did not know well the details of technique. Actually, the work was regarded as unnecessary. Although the valve seemed to leak, a seat leak of the valve may occur sometimes. Therefore, the operation of "inserting the blind plate" is specified in the work instructions. Considering the four days of successive rundown of off-specification product and the violation of work instructions, the major causes of the accident were lack of morals and insufficient education.

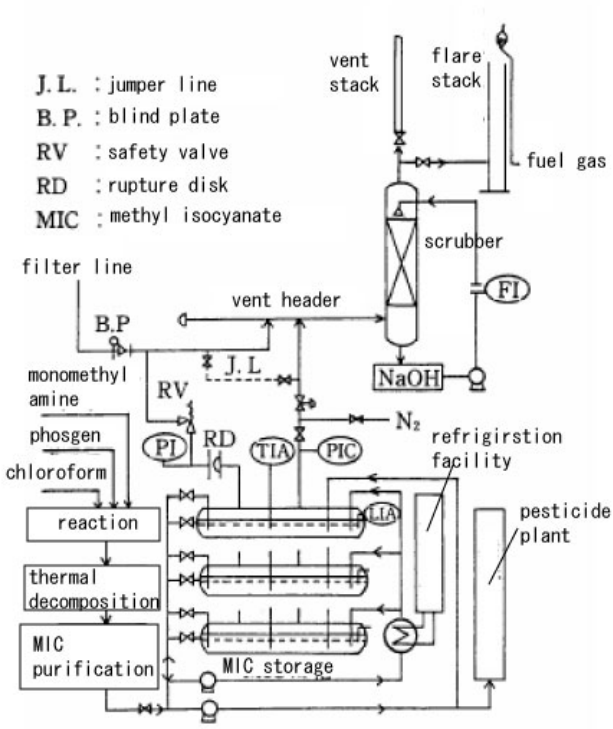

Fig. 2 estimated process diagram and safety equipment

In addition, all three kinds of safety devices failed completely, and MIC gas spread to the city. Three kinds of safety facilities had been prepared, as is described in the "Course" section above. However, the refrigeration unit had been stopped since July, and the scrubber had also been stopped on October 22nd when the manufacturing plant was stopped, possibly because it was judged to be unnecessary since it treated the process off-gas. Finally, the flare stack was stopped for piping work. Because of these reasons, the leaked gas was discharged out of the facilities without any

treatment. Although not directly related to the accident, there were some problems in the processing capacity. The maximum processing capacity of the scrubber was equal to eight tons of MIC. However, there was 40 tons of MIC in the tank at the time of the accident. The scrubber could not handle that much MIC. Furthermore, there were some questions regarding whether or not the processing rate was sufficient. Although the scrubber's processing rate should be designed for the total flow rate from the pressure relief valve and safety valve, the actual processing rate might not be sufficient. These issues indicate there were problems not only in the operation control but also in the safety design of the plant itself. It was regulated that the tank temperature must be lower than 0 ℃ because the MIC boiling point is just 39.1 ℃ and MIC is easily vaporized, but the refrigeration unit had been stopped over six months before the accident to cut down electrical charges by a certain opinion. Although it is not known whether or not the operation of the refrigeration unit could have prevented the runaway reaction directly, there is no doubt that refrigeration would have lengthened the time to the leakage.

The considerations above indicate that problems in operation management and process design were connected with the accident directly. However there was poor safety management basically. For example, there were three leakage accidents that caused the death of employees in December 1981, February 1982, and October 1982. In May 1982, the parent company carried out a research study on operation safety, and they indicated ten defective items including some fatal defects. However there was no written report that described the countermeasures to be executed.

The matters mentioned above appear to be the result of the abandonment of the safety management. The final products of the factory became out of date and business became depressed, for the rationalization of management, maintenance of facilities and employee education was neglected. Because of this competent engineers quit working at the company.

Besides, many factories and users of MIC but manufacturer of MIC had decreased the storage volume of MIC because of its dangerousness. Generally, MIC is used directly as an intermediate in the next process without storage. In France, MIC is stored only in small, stainless steel drum cans.

The more important problem is why the disaster became so large. There was no transmission of information regarding the dangerousness of MIC to the local government and inhabitants from the company. Therefore, emergency countermeasures were completely ignored by everyone, including the local government. There is no doubt that this fact resulted in the expansion of the damage. In addition, information

on the treatment of MIC poisoning was brought after the accident from the UCC headquarters and the U.S.A. disaster information center, but the information could not be transmitted to the doctors who were administering the medical treatment.

The main causes of the disaster are 1) that UCC decided to continue the manufacturing and storage of a large quantity of MIC without sufficient risk analysis and 2) that both UCC and UCIL did not make sufficient safety countermeasures due to a heavy deficit.

In other words, the disaster was caused by an almost complete lack of safe consciousness of the company. The technical capacity of UCIL was supposed to be much lower than UCC, and UCC had the responsibility for the plant construction. Guidance and execution of the safety techniques of a foreign subsidiary are duties of the parent company.

4. Process of cause elucidation

Although the most important point of the cause elucidation is "why the water leak into the tank occurred", there is no report that focused on that point. If MIC leaks and spreads to the city zone, human damage is inevitable considering the characteristics of the gas. It also became clear that the scrubber of the plant and the refrigeration unit for cooling had stopped from the operation record. The progress of the disaster can be described if the water contamination is proved. From the reports of the parties concerned and information about the works and the plant situations on and before the day when the disaster occurred, the water contamination route seemed to be specified. However, in the report by the parent company, it is claimed that an operator had injected water into the tank intentionally through the nozzle of the pressure gauge at the upper part of the tank where the accident occurred, based on the fact that the water hose was discovered nearby.

5. Immediate action

The leak was noticed by the shift leader, but he did not take any measures. Spraying of water was started after the gas accumulated near the tank, but the water did not reach the re. The police were contacted after persons responsible for the accident arrived. However, as shown above, appropriate measures had not been taken at all, and nothing could have been done after the leak.

6. Countermeasure

Countermeasures to prevent the recurrence of the accident were not taken, because

the factory was closed. As a general rule, facilities manufacturing, using or storing poisonous gas should carry out sufficient investigations and studies on the danger of the poisonous gas in order to ensure the sufficient safety of the facility and operation, to prepare against an accident by making appropriate contact with the local government and nearby inhabitants.

7. Knowledge

a) This accident is a typical example involving a company that is running a deficit. Accidents will occur if minimum safety countermeasures and safety education are neglected, even when management must be improved. It has been shown that keeping the safety is a minimum condition for the existence of a corporation.

b) There are many forms of toxic chemicals. Corporations that handle toxic chemicals in large amounts must understand that a major disaster can easily occur as a result of just one handling mistake, and they must consider appropriate countermeasures. Several milligrams or less of a toxic chemical may be enough to kill a person, and the pollution of a large region may be caused if a large quantity of the chemical is released. Safety is an important duty of the executive of a corporation, and it should not be left to lower-grade managers and operators. Although there are sometimes major accidents related to the energy industries including LPG or petroleum refining, accidents involving toxic chemicals can be much more serious with damaging wider area and causing serious sequelae to many persons, resulting in terrible disasters next to a major nuclear accident such as Chernobyl.

c) The accident was also a result of a problem of the overseas expansion of a large enterprise. The responsibility of the parent company for the safety of a foreign subsidiary in which the technology level is low is important. When the technology adopted by the foreign subsidiary is the technology of the parent company, or it is decided by the parent company, the final responsibility for the safety of the technology belongs to the parent company. In this accident, the parent company, which was a stockholder of over 50% of the foreign subsidiary, paid over 90% of the total reconciliation cost of 470 million US dollars, and the chairman was criminally accused. Although it is important to respect the individuality of the subsidiaries in the advancement overseas, a minimum safety management is an important obligation of the parent company and headquarters.

d) Safety equipment, including monitors and alarms for storage facilities, must not be stopped even if the manufacturing plant is shut down. Substitute measures

should be taken when the safety equipment is stopped, and the safety equipment should be restored as rapidly as possible.

e) Safety equipment such as scrubbers should have a sufficient processing rate and a capacity for treating the estimated discharge rate and quantity from safety valves and so on. Some buffer facilities are necessary to handle the situations where the rate is extremely large and a scrubber of sufficient size cannot be constructed.

f) It is important to carry out safety education, especially that of managers. The water washing of the piping, which might be unnecessary and was executed on the instruction of a site manager who had been transferred just before, triggered the accident. Education regarding safety and basic knowledge for management supervisors and operators working at the chemical plant was also important, considering that they did not insert the blind plate to the place where a leak may occur and they did not think that a valve may leak sometimes.

8. Influence of failure

The number of instant deaths just after the accident was estimated to be over 2000 persons, the final total of fatalities resulted from the accident was reported to be 14,410 at a reconciliation of the Supreme Court, and it was said that by December 2004, over 20,000 persons had died as a result of the accident. The total number of injuries was estimated to be 200,000 to 300,000 persons, including 20,000 persons who could no longer be employed and about 75,000 persons who were in pain with the sequelae.

As for the monetary loss to the corporation, the amount of the reconciliation payment was 470 million US dollars, and the stock price of UCC declined by 32%. Furthermore, the enterprise was forced to downsize, and the market sales per year of 9 billion US dollars dropped to 6.3 billion US dollars. In addition, although there were some other reasons involved, UCC was merged into another corporation.

9. On the side

A small violation of a discipline of a foreign subsidiary triggered the crisis of a large global corporation, and now, we cannot find the name of UCC in the world. From the standpoint of the parent company, the subsidiary was insignificant in scale and the share of the stock was not so large. The managers and employees of the parent company had to feel that “What happened to our company?” The safety management, especially the leakage control may need to be reconsidered in factories, particularly which handle toxic chemicals. As the reputation of a corporation in society will have a large effect on the continuance of the enterprise in the future, it is important to

consider and execute countermeasures against accidents and to ensure the essential safety.

In essence, the disaster was a typical result of a deficit company where safety was the responsibility of the parent company. From this point of view this disaster was completely the same as the criticality accident of JCO in Japan.

10. Sequel

This accident led to a civil suit to determine the compensation for damage in India and USA. Furthermore, in India, a criminal trial for accidents homicide by the chairman of the parent company was conducted. In 1989, the India Supreme Court issued a reconciliation order that the company should pay a total amount of 470 million US dollars as an indemnity to the victims of the accident, and both the India government and the parent company consented to the order. The stock price of the parent company also plummeted by over 30% in the aftermath of this accident, and in addition, a company about 1/10 in scale of UCC made a hostile TOB (take-over bid). As self-defense measures, UCC needed a huge amount of money, and as a result, the company was changed from selling the industrial gas and petrochemical products of the $ 9 billion sales a year to selling commodity chemical products of the $ 63 hundred million sales a year. When the 21 century comes, though there might be some other reasons, UCC was merged into a major chemical company, and at present there is no company existing with the name of UCC.

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