The Bhopal tragedy
Night of December 2 to 3, 1984
Bhopal
India

THE FACILITIES INVOLVED

The site:

In 1969, Union Carbide (UC), an American company, built a Sevin manufacturing plant in Bhopal, the capital of the Indian state Madhya Pradesh. Sevin is a powerful insecticide used particularly on tomatoes and potatoes. The license granted by the Indian Minister authorised the plant to produce 5,000 tons of Sevin per year.

Truck convoys are used to bring in the raw materials: Methyl isocyanate (MIC) and a-naphthol are trucked to Bhopal where they are transformed into pesticide. Two production units were built on the site: an a-naphthol facility in 1978 and an MIC facility was added in 1979. The MIC production facility was commissioned May 4, 1980.

The chemical complex near the railway station (1.5 km away), extends over more than 6.8 ha and employs 1,000 workers, most of whom can be considered as unskilled labourers. In order to compete with other pesticides (pyrethroids) on the market, UC initially decides to close this plant as it was not profitable (the site’s budget deficit: 4 million USD per year).

After negotiations with the Indian government, it finally decided to downsize numerous positions (including maintenance engineers…) and thus operate the installation for less money.

Synthesis of MIC and Sevin:

The reaction of MIC (\(\text{CH}_3\text{NH-COCl}\)) with a-naphthol leads to carbaryl (\(\text{C}_{12}\text{H}_{11}\text{NO}_2\)), known by its commercial name “Sevin”.

MIC is obtained by a reaction of phosgene, which is synthesized on site (\(\text{CO}+\text{Cl}_2 \rightarrow \text{COCl}_2\)), and monomethylamine (\(\text{CH}_3\text{NH}_2\)) in the presence of chloroform (\(\text{CHCl}_3\)). Impurities in the MIC develop according to the temperature and storage pressure. MIC decomposes rapidly in the presence of water, alcohols… and MIC itself (polycondensation). It must be stocked under nitrogen pressure and at 0 °C to maintain it in a liquid state. The vapour pressure of MIC at 0 °C is 0.267 bar and at 20 °C it is 0.46 bar. At Bhopal, the storage facility is maintained at a nitrogen pressure from 0.35 to 0.69 bar. When the pressure exceeds 2.76 bar, a safety valve opens, releasing the gases to a neutralisation tower.

The involved unit:

The installation consists of two liquid MIC storage tanks (E610 and E611) measuring 60 m\(^3\) (50 t) each. A third identical tank (E619), kept empty, is used as an emergency tank in case of an accident on the other tanks. This tank must not be filled to more than half its capacity. A rupture disc represents a hermetic seal between the safety valve and the contents of each tank. These horizontal, cylindrical stainless steel tanks (~2 m in diameter, ~ 13 m long), partially buried in a concrete casing, are interconnected between themselves and the MIC and Sevin reactors by a complex network of pipes equipped with valves. Each tank is connected to the following safety systems:
√ a refrigeration system constantly maintains the temperature of the MIC at approximately 0 °C to limit evaporation, polycondensation and reaction with impurities.

√ an exhaust gas scrubber or neutralisation tower or Vent Gas Scrubber (VGS) (Ø 1.7 m) implementing sodium hydroxide (NaOH) to neutralise the toxic gases in case of a leak or overpressure.

√ a flare stack (40 m high) burns gasses coming from the neutralisation tower and excess gases from a carbon monoxide unit (CO), the methyalmine storage vent and the vent from the MIC distillation unit's valve.

√ a water spraying system (water curtain) for diluting the vapours.

A wind sock indicates wind direction so that employees can avoid remaining downwind in case of a gas leak.

THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

The accident:

On December 2, 1984, the plant's senior management ordered that the pipes connecting the phosgene sector to the exhaust gas scrubber be cleaned. The operation started around 9.30 pm.

All the valves are closed at the time of the accident except the one leading to the safety valve and the rupture disc. The tanks contain 63 t of MIC: 42 t in E610 (filled beyond the designated limit), 20 t in E 611 and 1 t in E619.

On December 2, around 11.30 pm, operators reported a leak in the MIC storage unit which causes ocular irritation and a "dirty water" leak above MIC storage tank E610.

The pressure increases rapidly from 0.14 to 3.8 bar, the rupture disc bursts and the safety valve opens. When the chemical reaction had reached its peak (hydrolysis and polycondensation of the MIC), the pressure reached 13.79 bar and a temperature of 200°C. Tank E610 dilated under the heat, without yielding, and ruptured the concrete casing.

At 00.30 am, the plant's alarm is sounded. Twenty five workers are present at the site. The interconnecting valves with the other tanks are closed to limit the quantity of MIC involved. The scrubber’s control lever is activated although the indicator light remains off.

Around 1.00 am, fire nozzles and water curtains are used to dilute the toxic releases and cool down the tank.

Around 2.00 am, the police begin to receive the first calls concerning the accident.

At roughly 2.30 am, the siren warning the population is activated while 23 or 42 t of MIC (depending on the sources) had already been released into the atmosphere. The release of MIC stops around 2.30 am after the valve is closed, the pressure falling below the calibration threshold of 2.76 bar. The gases released are cooled in contact with the cold ambient air and move along at ground level as the MIC is heavier than air. A light wind from the N/NW directs the toxic cloud to the SE toward the shanty towns. It extends over more than 3 km and expands over an estimated 20 km² to 50 km², depending on the sources.

Around 5.30 am, the tank's temperature dropped to 45-60 °C. At 6.00 am, the temperature of the neutralising soda is 60 °C indicating that the gases passed through the VGS. However, draw of the soda had not been checked since October 23, 1984.
**Consequences of the accident:**

The data summarised below relative to the consequences of the tragedy are derived from press articles, investigation reports and videos...

According to an official report compiled by Indian authorities, there were 1,754 killed and 170,000 intoxicated, 12,000 of whom were in critical condition on the day of the accident. According to other sources, there were 2,500 deaths, 1,000 of which were children, and 200,000 injured, including 50,000 handicapped and 3,000 blinded for life. Between 500,000 and 600,000 were reported in 1998. The number of victims would climb to 3,350 dead in 1989 and 16,000 dead in 1998. In 2000, there were approximately 200,000 people with a chronic illness in Bhopal. Twenty thousand deaths were recorded in 2001. In 2004, the local authorities declare that 800,000 were effected and Amnesty International estimates the number of deaths from 22 to 25,000. Certain sources estimate that 15 to 20 new victims die every month as a direct result of the accident.

The victims suffer from a variety of serious pathologies (acute pulmonary oedema, respiratory distress, persistent coughs, blindness, juvenile cataracts, depression, neurological trouble, cancer, tuberculosis, arthralgia, gynaecological disruption, premature menopause, spontaneous abortion...). The infant mortality rate increased 300%. The uterus cancer rate is the highest in India. Indian doctors indicate that the contamination associated with the accident appears to be the result of the release of MIC associated with hydrocyanic acid. An Indian oncologist indicates that an increasing number of young people are stricken with cancer and leukaemia.

Livestock, dogs, cats and birds were also intoxicated: more than 4,000 animals were killed. The vegetation also suffered as a result of the toxic releases (defoliation...). The notable impact on agriculture resulted in socio-economic repercussions.

Chronic soil and water pollution had nevertheless existed prior to the accident due to the plants effluents, rich in heavy metals and toxic substances. In 1999, the soil still contained high quantities of mercury, chrome, copper, nickel and lead. In 2003, the levels of mercury were six million times greater than current standards. Chloroform, carbon tetrachloride and benzene were detected in water drawn from wells located to the south and south-east of the plant. Fruit and vegetables contain high quantities of toxic compounds. This chronic pollution, compounded by toxic releases have menaced the population for a long time.

Thousands of tons of toxic wastes are stocked in poor conditions, contaminating the public water system. Certain sources evoke the presence of 25,000 tons of solid waste stored at the site. A journalist affirms having noted mercury in pools, bins filled with toxic substances and sacks containing very dangerous chemical products in certain hangars. He also indicates that during the monsoon season, the rain becomes charged with toxic compounds and pollute the wells from which people drink.

**The 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 II’ directive on handling hazardous substances, and in light of the information available, this accident can be characterised by the four following indices:

1. **Dangerous materials released**: 6
2. **Human and social consequences**: 6
3. **Environmental consequences**: 1
4. **Economic consequences**: 0

The parameters composing these indices and their corresponding rating protocol are available from the following Website: [http://www.aria.developpement-durable.gouv.fr](http://www.aria.developpement-durable.gouv.fr)

The 23 or 42 t of MIC that have been released represent 15333 to 28 000 % of the Seveso threshold (0,15 t - MIC), which leads to a level of 6 for the “dangerous material released” index (according to parameter Q1).

Three parameters count in the determination of the level of the “human and social consequences” index : H3, H4 and H5.

- H3 parameter reaches 6, the number of death topping 50.
- H4 parameter reaches 6, the number of seriously injured people topping 200.
- H5 reaches 1 as default value, due to a lack of information regarding the number of injured.
The “human and social consequences” index thus reaches 6.

Three parameter count in the determination of the level of the “environmental consequences” index: Env10, Env12 and Env13.

√ The parameter Env10 is rated 1 by default, the number of animals or livestock impacted being unknown,

√ The parameter Env12 is rated 1 by default, the volume of polluted water being unknown,

√ The parameter Env13 reaches 4 : 5 000 tons of toxic waste are piled up on the 35-ha site.

The overall level of the “environmental consequences” index thus reaches 4.

Three parameter count in the determination of the level of the “economic consequences” index: €15, €16 and €18.

√ The parameter €15 is rated 1 by default, the costs of the destruction inside the plant being unknown.

√ The parameter €16 is rated 1 by default, the costs of the loss of production inside the plant being unknown.

√ The parameter €18 reaches 6: the elimination of the toxic waste is evaluated at 500 million dollars (> 20 M€).

The overall level of the “economic consequences” index thus reaches 6.

THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THE ACCIDENT

On November 30 and December 1, 1984, the operators attempt to transfer 42 t of MIC to the Sevin manufacturing unit. To do this, the tank must be pressurised above atmospheric pressure by adding nitrogen (N2) to prevent the influx of humidity. Due to a faulty valve, it is impossible to pressurise the tank, making it possible for any external contaminating product to enter the installation.

In the evening of December 2, 1984, a sliding closure, a physical barrier designed to prevent liquids from passing, is not replaced after the pipes were cleaned. It is the maintenance supervisor’s responsibility to ensure that the closure is in place, and his position had been deleted just a few days prior to the accident. It should be noted that the purge pipes are essentially blocked. However, the means in which the water was able to penetrate into tank E610 has not been clearly identified.

Water (500-1,000 l) enters tank E610 containing MIC due to a backflow through a connection between two pipes from one side to the gas scrubber, and the other to tank E610. In addition, it appears that this connecting pipe, installed in May 1984, is made of “easily” corrodible steel and not stainless steel as recommended in the Union Carbide technical guide.

The abnormal quantity of CHCl3 (12-16 % instead of 0.5%), present in the MIC storage unit at the time of the accident, results in distillation at an excessively high temperature between October 18 and 22. It is responsible for corrosion on the tank wall due to the formation of chlorines. This corrosion released ferrous ions which are catalysts in the trimerisation reaction of MIC. Since October 19, 1984, the day when production was stopped, the contents of the tanks had not been analysed.

The exothermic reaction of MIC leading to an increase in temperature is not detected by the temperature alarm which is out of service. The hydrolysis of MIC, producing dimethyluree and CO2 as well as the trimerisation, were instrumental in transforming liquid MIC into gaseous MIC, the increase in temperature and pressure which lead to the opening of the safety valve. The trimerisation heat of 40% of the MIC was sufficient to vaporise the remaining 60%.

The neutralisation and exhaust gas scrubber was taken out of service October 23, 1984. The flare stack used to burn the exhaust gases coming from the MIC storage facility had been disassembled a few days prior to the accident, allowing the release of toxic gases directly into the atmosphere.

The refrigeration unit had been shut down since June 1984 to reduce power consumption by 18%. As a result, the MIC was stored at ambient temperature (20 °C).

The 10m-hight water curtains implemented on the night of the accident had no effect on the drifting cloud of MIC which was released by a valve located at a height of 30m.

The following malfunctions and negligence identified in publications and inquiry reports relative to the accident are listed below:

Safety systems

√ the refrigeration unit shut down since June 1984,

√ the shut down of the exhaust gas scrubber, October 23, 1984,
√ dismantling of the flare stack for maintenance a few days prior to the accident,
√ high temperature audible alarms disconnected,
√ faulty temperature, pressure and MIC storage level indicators, verification of the parameters every hour in the beginning, then every 2 hours and, one month prior to the accident, every 8 hours,
√ water curtains poorly designed,
√ external alarm warning the population disconnected from the internal alarm alerting the personnel, and thus not triggered in a timely manner,
√ insufficient number of emergency exits: the plant was surrounded by a 2.5-meter wall topped with barbed wire, the majority of the emergency exits were blocked, the only door open in the zone were the gas was present made evacuation difficult,
√ no internal contingency plan,
√ tank E610 not under nitrogen pressure,
√ backup tank E619 partly filled.

Personnel
√ lack of personnel, personnel poorly qualified and trained,
√ no engineer present on the night of the accident, no instructions in the event of an accident P plug not installed on the piping during the cleaning operation as the order was not given (the maintenance manager’s position was deleted 11/26/1984),
√ the number of workers at the plant dropped from 1,350 to 950 in 4 years.
√ lack of information provided to the workers,
√ instruction panels in English, while the majority of the workers only understand Hindi.

Population
√ lack of information on the toxicity of the products
√ lack of evacuation and urbanisation plans.
√ lack of information among doctors the night of the accident: belied by UC on the use of sodium thiosulphate to treat hydrocyanic acid (HCN) intoxication, giving as a pretext that MIC is not dangerous and that no release of HCN was possible.

Photo D.R.  http://membres.lycos.fr/onirik31/inde/bhopal.html

Earlier audit reports
In May 1982, the Union Carbide Group sent a team of American engineers from its plastic materials and chemical products division in South Charleston to analyse the operation of the Bhopal plant and ensure that UC standards were respected. In their report they expose the disregard for operating and safety rules, and numerous acts of negligence (corrosion on pipes, the lack of automatic extinguishers in dangerous zones, deformation of equipment parts, the lack of pressure indicators, leakage of MIC, phosgene and chloroform, pipe ruptures, insufficiently qualified personnel…). They also indicated that a pipe was cleaned without plugging the ends of the conduit and which could thus lead to a tragedy.
**Previous accidents**

- December 24, 1978: 2 injured in a fire.
- December 24, 1981: a phosgene leak resulted in 1 death.
- January 10, 1982: an MIC leak intoxicates 18 or 24 people (depending on the source).
- February 10, 1982: a gas leak on a phosgene pump intoxicates 25 workers who had to be hospitalised immediately.
- August 1982: contact with MIC burns a technician over 30% of his body.
- October 5, 1982: toxic vapours are released after the rupture of a collar collected to several pipes in the MIC production unit, 4 victims.
- October 1982: a leak of MIC, HCl and CHCl₃ injures 3 workers and several people in the surrounding area.
- 1983: 2 victims
- January 1984: 1 death by inhalation of toxic gases

**ACTIONS TAKEN**

Operation Faith, under the control of the authorities and launched December 16, 1984, was designed to eliminate the MIC which remained in tanks E6111 and E619 after the accident. The purpose of the operation was to momentarily put the Sevin manufacturing plant back into production in order remove the remaining stock the MIC. All precautions were taken (tanks protected from the influx of pollutants, public informed of the operation, gas masks were distributed, safety perimeter established, ambulances, and the presence of a significant number of firemen and police...)

As the government of the State of Madhya Pradesh refused to renew the plants operating authorisation, the site was closed in July 1985, thus doing away with 700 jobs. UC and the Indian government negotiated compensation at 378 millions euros (470 million USD). This sum, paid on February 24, 1989 by UC and Union Carbide India Limited (UCIL) and managed by the Indian Central Bank, is partially blocked in an account. In 1989, in order to compensate all the victims, the authorities pay out the minimum authorised: 1,750 euros per death and 450 euros per injured.

In 1991, the Bhopal courts subpoena the president of UC to face charges of “criminal homicide”. The international warrant of arrest issued against him by the Indian courts via Interpol remains without effect, as well as the subpoenas presented in the United States by victim associations.

Blame was also directed toward the Indian government for not having followed the industrial plan of August 25, 1975 stipulating that plants at risks must be located 24 km from the city. In point of fact, the Minister of New Delhi had granted Union Carbide a license to operate its industrial installation less than 1 km from residential housing.

After this tragedy, UC stopped producing MIC in its various plants and left the Bhopal site "as is" after it was closed. In May 2004, the regional Indian government announced free health care for all victims and not just for the poverty stricken.

On June 24, 2004, the Indian government agreed to a judicial procedure in the USA requiring the American company buying UC to clean the site. The cost of eliminating the nearly 5,000 tons of toxic waste stored on the plant's 35 ha of property and in the surrounding region is estimated at 500 million dollars.

In July 2004, the Indian Supreme Court ordered the Central Bank to release the rest of the money paid by UC in 1989 as soon as possible and to distribute it among the victims. The start of payments was announced for November 15th.

On December 16, 2004, the European Parliament requested that the governments of the State of Madhya Pradesh and India rapidly undertake decontamination and cleanup of the site. The euro-MPs noted that the chemical products left on site continue to pollute the water supply network causing cancers and congenital deformations. They request that India ensure a regular supply of drinking water. The resolution adopted by the European Parliament suggested that the EU address how to assist in the decontamination and supply of water. The European Commission stated that it was ready to assist the country in its strategy. The deputies also would like that the victims benefit from more substantial compensation and better treatment.

Initiated in 1987, these legal proceedings were somewhat chaotic. Charged at first with homicide, the 8 detainees (7 Indians and the American company President) then benefitted from a 1996 Indian Supreme Court injunction. The highest tribunal of the nation ruled that the case should be tried as homicide by negligence, a misdemeanour punishable by at most two years of prison.
In 1989, the operator signed an agreement with the Indian government: the industrialist would pay compensation in the amount of $470 million in exchange for dropping all charges.

On June 7, 2010, the Bhopal Court of First Instance sentenced to two years of prison and 100,000 rupees (€1.751) in fines 7 individuals deemed liable for the disaster. A $10,000 (€8,354) fine was imposed on the operator's Indian subsidiary for negligence. The company's CEO at the time, declared by the court as a "fugitive", was not specifically named when the verdict was announced.

LESSONS LEARNT

This catastrophe is the worst disaster in chemical industry history. These tragic consequences underscore the high price paid by the surrounding population due to the lack of safety from a unit which presented such a high risk. Elementary risk management measures must be applied over time:

- √ reduction of risks at the source by organisational and technical measures,
- √ residential areas must be sufficiently far away to limit exposure of populations,
- √ a contingency plan designed according to the danger potential, and
- √ preventive information for the population relative the risks to which they were exposed was either forgotten or ignored.

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