

BHOPAL AND THE GLOBAL MOVEMENT ON PROCESS SAFETY

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The accident at Bhopal on the night of December 2–3, 1984 was the world's worst accident, resulting in the immediate death of approximately 4,000 and the subsequent death of over 16,000, with life long injuries suffered by over 200,000 followed by genetic mutations to affect several generations of offsprings. The pollution of water bodies is affecting several hundred thousand more. No other recorded accident anywhere in the world has produced even 10% of the above casualties and life-long effects.

In this paper, we will briefly describe the accident and the significant effects it has had on regulations, process development and design, training, teaching, RD, etc., all impacting process safety.

INTRODUCTION

It is worth quoting from my recent editorial[1] "Charles Perrow of Yale University states in his seminal work '*Normal Accidents*'[2]: "The accident that released deadly methyl isocyanate gas (MIC) in Union Carbide's Bhopal, India, plant in December 1984, resulting in at least 4,000 'prompt' deaths and over 200,000 injuries, was for me the most theoretically significant catastrophe... In the words of one of the most interesting clichés in this business, 'It was an accident waiting to happen'. But ... the equally common cliché 'we were lucky it wasn't worse' for once does not hold. Bhopal was that rare accident that could hardly have been worse; they are hard to arrange". He calls it the 'Union Carbide factor'."

There are numerous books and authoritative reports on the Bhopal accident. References 3 to 12 is a very short listing of them. Each one reveals something new and one may wish to read them all, if available. The brief description here has been compiled from these books, news reports, discussions with the then Union Carbide employees, several visits to Bhopal and the UC plant. Very briefly, the accident in Bhopal released 41 tonnes of deadly MIC and its reaction products (Table 1)[4] in the middle of the winter night of December 2–3, 1984, approximate time 12:40 AM to 2:30 AM. The release occurred mainly from the top of a 30-m (100 ft) high release vent. It moved as a wall, approx. 10 m (30-ft) high, and swept over the nearby residential areas, the railway station and the major hospitals, covering an area of approx. 65 sq. km (25 sq. miles). There was no warning from the company to the city administration about the release or the toxic nature of the gas. Initially the company even denied the leak from its plant.

> **'The gas leak just can't be from my plant. The plant is shut down. Our technology just can't go wrong; we just can't have such leaks'.**
> (Union Carbide Work's Manager when told of the leak over the phone)

Table 1. Analysis of representative core samples from tank 610[4]

Methylisocyanate trimer (MICT)	55.71%
Dimethylisocyanurate (DMI)	21.42%
Chloride	4.33%
Trimethyl amine (TMA)	3.384%
Dione	3.13%
Dimethyl amine (DMA)	1.978%
Trimethyl urea (TMU)	1.52%
Dimethyl urea (DMU)	1.29%
Monomethyl amine (MMA)	1.02%
Trimethyl biuret (TMB)	0.94%
Tetramethyl biuret (TRMB)	trace
Metallic ions:	
Iron (Fe)	1,275 ppm
Chromium (Cr)	260 ppm
Nickel (Ni)	95 ppm
Sodium (Na)	60 ppm
Cadmium (Cd)	20 ppm
Magnesium (Mg)	3 ppm
Other compounds detected at UC Head Quarters:	
Ammonium chloride	
Methyl substituted amine hydrochlorides (DMA-HCl, TMA-HCl)	
Central Pollution Control Board study: Traces of Cyanide	

MIC has a TLV of 0.02 ppm and a density twice that of air. So it clings to the ground devastating anyone who breathes it. There were several thousand immediate deaths and, in the next few days, the toll mounted to approx. 8000. While the exact number is not known and may never be known, just like the exact composition of what all was released that night is not known, it remains uncontested that the deaths, during the following days and weeks, numbered several thousand.

'... the first time in recorded human history that almost a whole town was gassed in peace time'.
(Wil Lepkowski, C&EN, Feb. 11, 1985)

Those who survived suffered from numerous ailments affecting all parts of the body including the reproductive organs that have affected the next generation. A listing of some of the ailments that the victims suffered from is in Table 2. There were numerous factors that contributed to the accident. Several are in Table 3.

Table 2. Broad symptoms of victims arriving at the hospitals

- Severe chest congestion (100% cases)
- Foreign body sensation in the eyes
- Diminished and blurred vision
- Whiteness in the eyes
- Frothing at the mouth
- Headache and giddiness
- Sore throat
- Pain and burning sensation in the chest
- Vomiting
- Abdominal cramps
- Diarrhea
- Swelling of legs
- Palpitation
- Vomiting of blood
- Weakness of tongue and limbs
- Paralysis
- Stupor
- Chills
- Cold/clammy skin
- Coma
- Fever
- Numerous pregnant women aborted spontaneously, their children stillborn

Post-mortem Reports

- Cerebral oedema
- Massive pulmonary oedema
- Massive destruction of lung tissues
- Massive coagulation of blood leaving parts of circulatory system drained of blood
- Damaged liver and kidneys
- Increased levels of polymorphs and blood urea
- Long-term and secondary effects
- Effects on plants, fish, birds and animals
- Effects on air, water, ground water
- Long-term treatment and livelihood of the effected masses.

A survey of about 250,000 victims indicated that[4]

- 85.4% Moderate to severe illness
- 94.6% Respiratory problems
- 90.7% Eye Problems
- 53% Gastronomical problems
- 43.6% Neuromuscular problems

(*Continued*)

Table 2. *Continued*

Some of the psychological and emotional problems encountered were[4]:
- Lack of sleep
- Nightmares
- Anxiety
- Loss of libido
- Increased family violence
- Impairment of learning abilities in children
- Stillbirths, abortions, premature deaths and malformations

Thousands of cattle died and standing vegetation was destroyed.

Delhi Science Forum Report 'Bhopal Tragedy: Looking Beyond', in Ref. 5

The doctors, several hundred of them, worked around the clock. Their effectiveness was compromised by lack of authentic information about the gases that had leaked and the antidotes for them. The company continued to maintain that the gas was only a minor eye irritant and the victims would not have any long-term effects. Bhopal also saw the immediate arrival of several non-governmental organizations (NGOs), media persons, politicians, Union Carbide officials, accident claims lawyers from the USA (their compensation suits added up to $100 Billion[4]), and international chemical warfare experts.

> **'I can say that I have seen Chemical Warfare. Everything so quiet. Goats, cats, whole families – father, mother, children – all lying silent and still. And every structure totally intact.'**
> (Dr. R. K. Bisarya, Mayor of Bhopal, December, 1984, quoted in C&EN, Feb. 11, 1985, p 26)

At the time of the accident, the plant was for sale[4]

Union Carbide offered to pay $200 million in compensation over a period of 30 years. It was insured for that amount. It hired a renowned public relations firm to improve its image.

Contrary to what is generally known, the area where the plant was located had the railway station for over a hundred years, and many middle class localities. The initial license for the plant was for formulations, it gradually got enhanced to manufacturing. The municipal authorities continued to object to the UCIL plant since the site was designated for commercial or light industrial use, not hazardous industries. However, UCIL was a powerful company. Many officials' wards were employed[4]. A District Magistrate had ordered the removal of the MIC storage to a site farther away from the population. The company dragged its feet until the official was transferred at the end of his tour of duty. It is however a fact that many rural people moved to the neighbourhood of the UC plant in the hope of getting some job, any job. They were the ones who paid the ultimate

Table 3. Factors contributing to the accident[4]

Design

- The plant was overdesigned by 150%, at the insistence of the UC Headquarters and against the advice of the UC personnel in Bhopal. This led to losses and cost cuttings due to lower capacity utilization: 2308 T in 1982, 1647 T in 1983 and <1000 T in 1984. Losses in 1984 were ~$4 million
- Computerized early warning system and data logger were not incorporated into the design
- Process design allowed for long-term storage of very large quantities of MIC in tanks
- A non-MIC route could have been chosen as was used by UC earlier
- A continuous reactor design could have done away with MIC storage. Any reactor leak would have released a few kg, not tons of MIC and would not have affected beyond the plant boundary
- Water sprays were designed to reach only 12–15 meters although the gases from the flare were released at 30 meters
- Jumper line design modification connected relief-valve vent header and the process-vent header, allowing water ingress into the storage tank
- Maximum allowable scrubber pressure was 15 psi while the rupture disc allowing the gas to come into the scrubber was set at 40 psi
- A single stage, manual safety system was used in place of an electronically controlled four-stage back-up safety system used in other similar plants
- The design did not provide a backup system to divert escaping MIC to an effluent area for quick neutralization as in Bayer's MIC plant

Equipment

- New plant was built in 1981 but poorly maintained
- Instruments and gauges were unreliable
- Valves and pipes were rusted and leaking
- Refrigeration unit (30 ton capacity) was too small to be effective in runaway reactions
- Safety and operating manuals were in English, not easily readable by all operators
- Highly toxic MIC and phosgene gases were used as basic raw materials without their toxic effects being made widely known
- MIC in tank 610 was contaminated with a higher chloroform level than allowed

Operating Procedure and Personnel Training

- Failure to pressurize tank 610 with nitrogen was ignored repeatedly
- Refrigerant unit was shut down several months before the accident to save on the electric bill (approx. $20 per day)
- Flare tower and scrubber were simultaneously non-operational while large amounts of MIC were in storage
- Spare tank was not empty for the operators to transfer MIC into it

(*Continued*)

Table 3. *Continued*

- Tank 610 was filled to 75% to 80% of capacity so the pressure rose faster. Recommended filling was about 50% of the capacity
- Lessons should have been learned from earlier MIC releases and accidents, including a fatality
- Water flushing of pipes was re-ordered without investigating what was preventing water from coming out of the other end
- Recommendations of a UC team in 1982 to improve safety standards were not fully complied with
- The staff had been cut to less than 50%. Many experienced staff left UC
- New staff was given significantly reduced training
- New staff was told only that MIC could irritate their eyes or rash their skin
- UC had one safety official for all its plants in India. He sat at the Bombay Office and kept the safety manuals updated
- The alarm had been turned off after a few minutes as per the company policy
- The civic authorities should have been told about the toxic nature of MIC and other chemicals at site. Emergency plans to rescue he people should have been prepared. Doctors should have been told the antidote
- UC should have presurrised the authorities to not let the shantytown come up at its boundary. That probably would have required it to disclose the extremely dangerous nature of its chemicals

price. Those who reaped the benefits of the UCIL plant – workers, rich farmers, stockholders and government agencies – escaped unharmed.

One should not think that since Bhopal happened in a developing country, such accidents cannot happen in the developed countries[13]. It may be of interest to know that an EPA report points out the fact that in 25 years preceding 1989, there were 17 accidents of toxic release in the US that exceeded in volumes and levels of toxicity the Bhopal release. However, the lack of habitation in the areas of these releases saved casualties[14].

SOME GLOBAL CHANGES USHERED IN BY THE BHOPAL TRAGEDY[15,16]

(Those marked with an asterisk * are expanded upon later on)

- The public, media, legislators, governments, judiciary, lawyers, sociologists, psychologists, economists and non-governmental organizations (NGOs), etc. became more active forcing companies to conduct their operations safely.
- Companies drastically reduced storage inventories, imparted better training, and adopted ‘Responsible Care’ programme to involve communities*.
- Governments enacted several legislations and made their enforcement stricter*.
- Accident investigation became more thorough and significant liabilities are imposed on the erring parties by the courts.

- Colleges started teaching about safety. SACHE (CCPS) produces instruction material in the form of lecture notes, slides, videos, etc. It also conducts 4-day hands-on training course at a major US corporation for the teachers, fully subsidized.
- All companies have started vigorous training programmes for their new recruits as well as for the existing work force.
- EU has set up Joint Research Council (JRC) and European Centre for Process Safety (ECPS). AIChE has set up the Centre for Chemical Process Safety (CCPS). Indian Government has set up a Disaster Management Institute (DMI) in Bhopal.
- Some networks have been formed, mainly in the U.K., to maintain continuing interaction between researchers with similar interests. Some of these are the Process Risk Network, Green Chemistry Network, Crystal Faraday on Green Technology, Process Intensification Network.
- Numerous conferences, workshops and short courses are held annually around the world by professional societies, consultants, regulatory bodies, etc.
- Many authoritative books and conference proceedings have been produced, amongst others, by AIChE, CCPS, HSE, IChemE, EPA, FEMA, ILO, DO, WHO, World Bank, IAEA, as well as by the commercial publishing houses. Several prominent journals are now published in the field: Journal of Loss Prevention in the Process Industries, Journal of Hazardous Materials (existed already), Process Safety Progress, Process Safety and Environmental Protection, Loss Prevention Bulletin, Green Chemistry, MKOPSC Centerline.
- Many research projects worldwide are being amply funded by governments and some industries. Various mathematical models have been formulated to model fire, explosion and toxic gas dispersion. Software is also available on these topics*.
- Several new initiatives have been undertaken in process development and design. Some of these are: Inherently Safer Design, Reactive Separations, Process Intensification, Green Chemistry, Clean Technologies, Green Engineering, Sustainable Development, Life-cycle Costs, Process Miniaturization, Micro-reactors, Disposable Plants, BRITEST (Best Route Innovation Technology Evaluation and Selection Techniques)
- Several process safety related web sites have come up around the world.
- Local people, living near a hazardous process facility, have also become active to ensure safety*.
- Movement towards safety has since 1990s, saved several hundred to a thousand lives, many thousand serious injuries, lots of trauma to families and millions of dollars in losses and compensation.
- Awards recognizing work in process safety have been setup as a means to encourage work in this area. Awards are given by IChemE, IIChE, SACHE (to students), MKOPSC, Presidential Green Chemistry Awards, amongst others.
- Apart from the national organizations in each nation, numerous international organizations are involved. Some are: International Labour Organization (ILO), World Health Organization (WHO), United Nations Development Programme (UNDP), U.N. Environmental Programme (UNEP), The World Bank (WB), Asian Development Bank (ADB).

- Working in safety related areas in companies or academics is not considered as dead end or third class career.

Some of the above are further expanded below.

RESEARCH AREAS

Active research is going on in several academic and industrial organizations. The number of such research personnel is inadequate at present but it is gradually increasing. Public image contributes a lot to severity of legislation, students opting for careers in chemical engineering, location of plants, funding of research, etc. Hence, it is in a chemical engineers' interest to work to make the industry safer. Even with the limited number of researchers currently involved, the areas being surveyed are numerous and vast. Some are listed below in no particular order of importance/preference:

Explosion Prevention and Suppression, Reactive Separations, Catalysts for Enhanced Selectivity at Moderate Operating Conditions, Process Intensification, Process Miniaturization, Reactive Chemicals, Use of Nano Technology for Hazardous Substances, Flammability Limits of Mixtures, Inherently Safer Design, Higee Distillation/Separations, Early Detection of Gas/Liquid Pipeline Failures, Fast Sensors and Control Systems, Risk Analysis, Accident Investigation Methodologies, Flashing of Liquid, CFD Modeling Fire, Explosion and Toxic Gas Release under Real World Situations; Early Detection of Temperature and Pressure Rise, Process Security Management, Handling Simultaneous Multiple Events, Management of Change, Site Planning, Transportation of Hazardous Substances, Calculation of Fire Water Requirement for Hydrocarbon Tank Fire, Hazards of Pesticide Fires, Dust Explosions, Software for Automated Hazard Analysis, Pressure Vessel Design to Withstand Shock Waves, Flow through Cracks and Holes with Aerosol Formation, Work-Permit System, Off-Shore Platforms (a large research discipline), Safety Concerns of Computer-Controlled Plants, Conversion of Batch Plants to Continuous Plants, Design of Safety Relief Valves and Systems, Effect of External Fire on Process Vessel Integrity, Data Integrity and Correlation, On-line Fault Diagnosis, Design of Flare Towers for Worst Case Scenarios, Development of Non-flammable and Non-toxic Solvents, etc.

LEGISLATION

This is one area that has received the maximum attention. The changes have been dramatic. A very good survey of the current international industrial safety management frameworks has been given by Kirchsteiger[17]. He brings out multilateral activities which involve international organizations, such as: Council of Europe (OE), European Bank of Reconstruction and Development (EBRD), European Commission (EC), International Labour Organization (ILO), International Programme on Chemical Safety (IPCS), International Atomic Energy Agency (IAEA), International maritime Organization (IMO), UN Environment Programme (UNEP), UN Industrial Development

Organization (UNIDO), UN Economic Commission for Europe (UN/ECE), Organization for Economic Co-operation and Development (OECD), World Health Organization (WHO), The World Bank (WB), and the North American Treaty Organization (NATO). It is very encouraging to know the vast number of international organizations that are involved in making the chemical industry and chemicals safer and provide assistance in case of need.

Responses received from several experts in the field[18–23] bring out the facts that there has been a great impact of Bhopal accident on legislation in many countries, though in the UK, a significant deal had already been achieved after the Flixborough accident.

In India, 14 Acts of Parliament have been enacted since 1984. Detailed rules have been formulated for their implementation. District-wise Hazard Survey of Major Hazardous Industries has been carried out in over 45 industrial districts countrywide to help prepare the emergency plans, both on-site and off-site.

In the USA, the first act that was passed after the Bhopal tragedy was Emergency Planning and Right-to-Know Act (EPCRA) of 1986. It was an act with very broad coverage, which was further expanded to include local emergency planning committees, etc[24]. The US Congress also gave instructions to OSHA and EPA. OSHA has, under 29CFR1910.119, put together Process Safety Management (PSM) System consisting of 14 elements. EPA has, under the 1990 Clean Air Act Amendments put together a Risk Management Plan (RMP). A good survey of US rule making is given in References 24 and 25. The terrorists' attacks of 9/11 have added urgency to security of chemical plants that store huge amounts of energy.

In the Netherlands, all establishments that fall under the Seveso directive have to submit (or have available for inspection) the information on major hazard prevention policy, list of chemicals, internal emergency plan, safety report, technical measures if demanded[26]. The same holds for several other countries like Belgium, Germany and the UK though a couple of these require a QRA and are also more restrictive with regards to the technical measures. France requires QRA and further information under several headings. There are also regulations regarding land use (or spatial) planning in all of the above European countries. These prescribe the acceptable probabilities of local and societal risks. These got enacted primarily after the Bhopal tragedy.

In the U.K., several acts have been enacted and modified with time. It would be difficult to say that they were enacted due to Bhopal since several were in the works before. However, Bhopal did encourage the authorities to take a fresh look since now the climate was right to include items that industry would probably have raised hue and cry against in pre-Bhopal time. CIMAH to implement Seveso 1 and then COMAH to implement SEVESO 2 are amongst the important ones, as also NIHHS. UK's later laws, DSEAR (Dangerous Substances and Explosives Atmospheres Regulations) and MGHSWR (Management of Health and Safety Regulations) include requirements of inherent safety[21].

Numerous laws have also been enacted in Germany, which is a major producer and exporters of chemicals and pharmaceuticals and has global operations with subsidiaries located worldwide[19, 27].

Governments have imposed several further requirements on the industry. In India, an industry employing above a certain number of workers has to have a trained 'safety officer' on roll. Training programmes of one-year duration, to prepare one as a Safety Officer, are run by Regional Labour Institutes and other recognized bodies. A 'Public Liability Insurance' (PLI) has to be taken out by each industry equivalent to its paid-up capital to compensate the public affected by its activities. The compensation is paid out immediately while the courts decide the liability factor and subsequently impose penalties.

Most governments encourage the use of Inherently Safer Design concepts. Contra Costa County in California is the first one to mandate its use. A company in this county has to convince the county if it is not using ISD concepts.

There are international regulations of prior information about the movement of hazardous materials between countries.

ACTIONS BY INDUSTRY

Immediately after the Bhopal tragedy, the industry woke up from its slumber. Individual industry reduced its storage inventory to a very significant extent, and started working with 'just-in-time' delivery concept. Plants with smaller reactor volumes were designed and an exciting new discipline of Process Intensification has sprouted up.

Several multinational companies exerted efforts to ensure that the standards of safety in their plants worldwide were the same as their home-based ones.

A vigorous training programme started and thousands of operators, engineers, supervisors and managers have been trained in process safety in the years following the Bhopal tragedy.

The industries associations started 'Responsible Care' programme. At the 10-year anniversary of the launch of 'Responsible Care', Trevor Kletz indicated that several hundred to a thousand lives had been saved over that period.

ACTIONS BY LOCAL PEOPLE

Local people living near a hazardous plant have formed groups to monitor the plant performance with regards to safety and environment. The idea is not to dislodge the industry which plays an important role in the economy of the community by providing jobs and taxes. The working together with companies reinforces mutual confidence and prompt relief actions should something go wrong.

UN Environment Programme has issued APELL (Awareness and Preparedness for Emergencies at Local Level). This has been adapted by many countries and is being implemented to reduce the chances and severity of catastrophic disasters and their consequences, should they still occur.

CONCLUSIONS

The process industry is a big contributor to the nations' wealth and provides items of daily needs for the masses. Hence its safety has to be ensured and its public image restored. Public's involvement in decision making will be very helpful on both counts.

Since multinational corporations are often more powerful than the governments of the countries they operate in, they bear an almost government-like responsibility for the well-being of the people who live near their plants.

As Bhopal so tragically demonstrates, the price of safety is eternal vigilance. Communities and individuals ignore this lesson at their own peril. The governments, legislators, law enforcement agencies, civic services, media and the NGOs also have to remain alert. Industry must improve its safety performance enough to win public trust.

The results of the process safety movement in the last 15 years have been a significant reduction in accident rate when compared on the basis of production volume or value.

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