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The Accident in Bhopal: Observations 20 Years Later

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Abstract

The most influential process safety accident passed its 20th anniversary on Dec 3, 2004. At an international symposium to mark the event in Kanpur, India during the week of this anniversary, process safety practitioners from around the world assembled to discuss progress in resolving the Bhopal tragedy and in advancing the practice of process safety worldwide. This paper reports the main conclusions from the conference, and provides insight into the Bhopal site as attendees found it in December 2004. Since 1984, many positive steps worldwide have been made in regards to improvements in process safety and protection of personnel within chemical plants and of people in the surrounding communities. However, little progress has been made in decommissioning and decontaminating the Bhopal plant site, now under control of the Indian state of Madhya Pradesh. Many plant chemicals, abandoned there in 1985, were still at the site in 2004, mostly in sub-standard storage conditions. Mitigation recently commenced, but unconfirmed reports of the mitigation methods are concerning. The lesson learned: we all have a responsibility to insure that events which follow a chemical accident reach a proper conclusion; and that no further undue suffering results to the general public and our fellow employees.

1. Introduction

1.1 Background about the original accident

1.1.1 The pesticide plant and the MIC release

Much information about the original Bhopal accident is available through books [1, 2, 3], journal reports [4] case histories [5], documentaries [6, 7], proceedings from international conferences,[8, 9], and the Internet [10, 11, 12]. In essence, about 41 metric tons of methyl isocyanate was released from the Union Carbide India Limited (UCIL) pesticide plant in Bhopal just after midnight on December 3, 1984. This gas spread slowly southward from the plant site during the early morning hours with very stable weather conditions. Of the 900,000 population within the city, over 200,000 people were exposed to MIC tainted air. Documented death counts are listed at 3,787 [13]. The number of undocumented deaths will never be known, but estimates are over 10,000. Chaos surrounded the city afterwards. Thousands panicked. As the story of the disaster circled the globe, international aid began to flow into the city. Union Carbide, USA, was the majority owner of the plant (50.9%) with Indian investors owning the rest [14]. Warren Anderson, then chairman, made a personal trip to the India to reach out, only to be placed under arrest. Several years later Union Carbide settled with the Indian Government for over $470 million dollars plus other considerations[15]. The event that caused the release was traced to a runaway reaction created by the contamination of a storage tank of methyl isocyanate with a substantial amount of water. Although the safety relief valve opened at design pressure, all downstream measures to mitigate an external release of MIC to the surroundings were on stand-by (a caustic scrubbing tower) or out-of-service (a flare tower). Furthermore, a water curtain spray designed to mitigate releases did not reach the elevation of the release plume. Thus, MIC exited at an elevation from ground level of approximately 35 meters for a period of 15 to 30 minutes. The cloud then descended to ground level (MIC gas is approximately 2 times as dense as air), infiltrating the surrounding residential areas (illegal shanty towns), and flowing slowly towards the center of Bhopal, located about 2 km to the south.

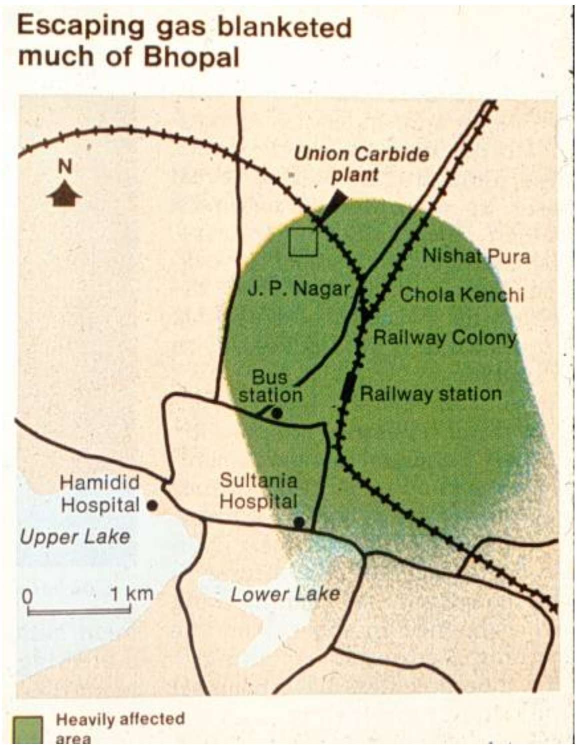

Fig. 1. Overview map of the Bhopal vicinity.

The UCIL plant manufactured Sevin®, a Union Carbide trade name for a pesticide, whose active ingredient is 1-napthyl-N-methylcarbamate, or the generic name carbaryl. The reaction involved two reactants, methyl isocyanate (MIC) and alpha naphthol. Methyl isocyanate is reactive, toxic, volatile, and flammable. The maximum exposure (TLV-TWA) during an 8-hour period is 0.02 ppm (20 parts per billion). By comparison, phosgene, another extremely toxic gas, has a TLV-TWA of 0.1 ppm (100 parts per billion). Individuals begin to experience severe irritation of the nose and throat at exposures to MIC above 21 ppm. The LC_{50} for rats exposed to MIC vapors in air for 4 hours is 5 ppm. In humans, exposure to high concentrations can cause enough fluid accumulation in the lungs to cause drowning. At lower levels of exposure, the gas affects the eyes and lungs. It acts as a corrosive agent, eating away at moist vulnerable tissue, such as mucous membranes and eye surfaces. Long-term effects also exist. MIC has a boiling point of 39.1^{o}C and a vapor pressure of 348 mm Hg at 20^{o}C. As such, it is quite volatile and it will easily enter into the surroundings at very high concentrations. With a molecular weight of 57, about 2 times that of air MIC has a higher vapor density compared to air.

1.1.2 Explanation of the Possible Causes

Several causes have been proposed, two of which have been subjected extensive examination. Cause 1 captioned in Fig. 2, is the admission of water via a water cleaning process where an isolation valve existed but the line had not been blanked off (the “Water Washing Theory). This isolation valve was located about 300 m from the storage tanks via a pipeline. Substantial water (500 kg plus line volume) with some head was required along with one other key valve leaking. Cause 2 was sabotage, deliberately connecting a water hose to piping that directly entered into the storage tank and deliberately admitted water. Cause 2 would have required intimate knowledge of piping around the tank, where to physically make the correct connection, and the removal of a pressure indicator and then the re-attachment of piping fittings.

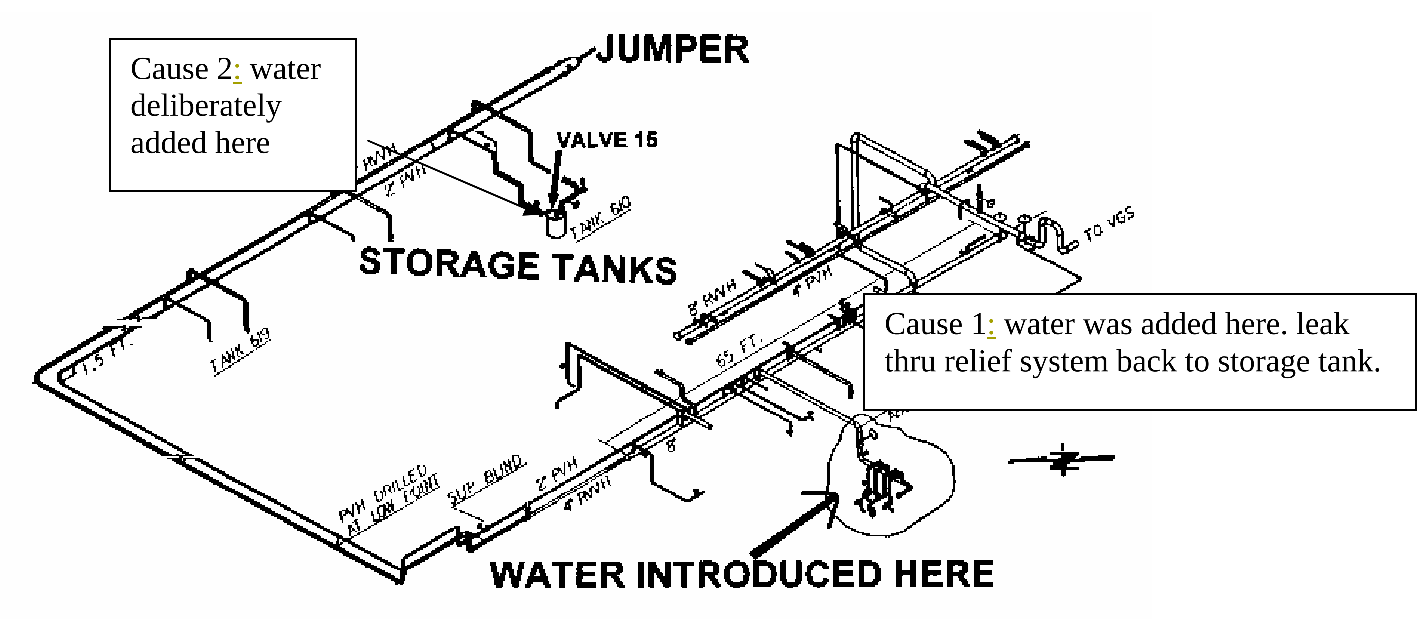

Fig. 2. Overview of the piping system.

However, neither is a root cause. The root causes were management decisions:

a decision to neglect a flare system in need of repair;

- a decision to place a scrubber system on stand-by to save on operating expenses;
- a decision to remove coolant from the refrigeration system used to cool the MIC storage tank.

And, there are additional root causes which made the incident more severe:

- inadequate emergency planning and community awareness;
- lack of awareness of the potential impact of MIC on the community by the people operating the plant; lack of communication with community officials before and during the incident;

- inadequate community planning, allowing a large population to live near a hazardous manufacturing plant. This situation was not unusual in the chemical industry in the early 1980s, and one major impact of Bhopal was to warn all chemical plants about the importance of these considerations in the siting and operation of facilities.

1.1.3 The Plant Layout 1984

Shown in Fig. 3, Fig. 4, and Fig. **5**, are engineering details related to the storage of MIC at the Bhopal plant. The plant was "backwards" integrated from a formulation plant to a fully integrated chemical plant in the late 1970's. Fig. 3 is a photograph looking North where the 3 MIC storage tanks were surrounded with earth for insulation (on the right side, or towards the East side of the plant layout). Fig. 4 shows a cross section of the storage tanks with piping provided for internal cooling, MIC flow in and out, and attachment to the process vent system via a relief valve should the tanks be overpressurized. Finally, Fig. **5** shows the effluent treatment system downstream of the relief valves, for treatment of any material that might be discharged if the relief valve opened, either due to overpressurization of an MIC tank or because of a relief valve leak.

Fig. 3. Photograph taken shortly after the accident. A pipe rack is shown on the left and the partially buried storage tanks (three total) for MIC are located mid photo right.

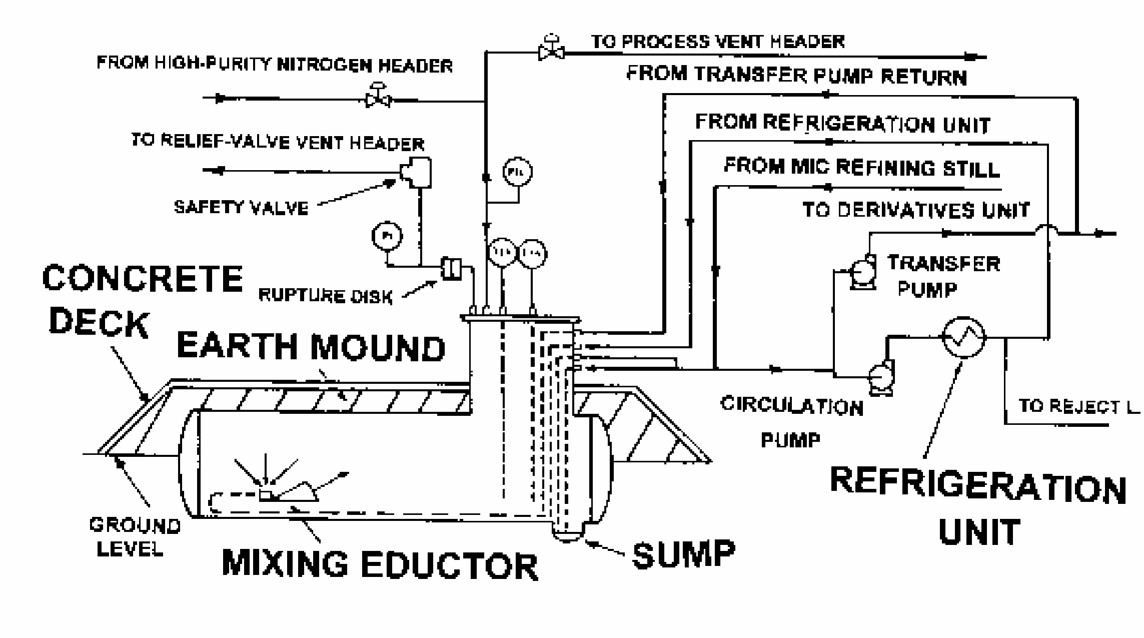

Fig. 4. Engineering piping details around the storage tanks. Storage tanks could hold up to 40 metric tons of liquid MIC.

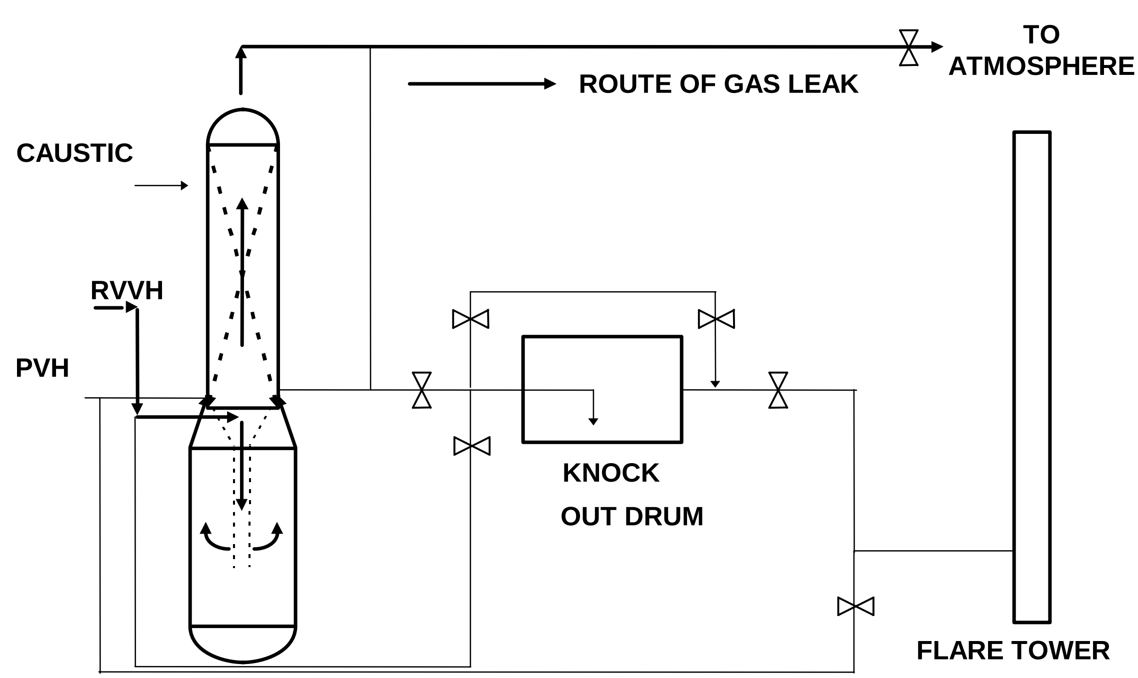

Fig. 5. Schematic of emergency relief effluent treatment system that included a scrubber and flare tower in series.

1.2 The 20th Anniversary of the Bhopal Gas Tragedy

On December 1 to 3, 2004, Prof. J. Gupta of the Indian Institute of Technology – Kanpur organized the "International Conference on the 20th Anniversary of the Bhopal Gas Tragedy," in Kanpur, India [16]. The focus of the conference was the Bhopal tragedy and its effects on process safety. Process Safety representatives from around the world attended. Papers from this conference are available in print [9] and on the Internet [17]. Perhaps the most memorable presentations were the first hand witness stories from Bhopal residents and UCIL workers. For example, Swaraj Puri, the chief of police of Bhopal described how, exposed to MIC vapors, he risked his life seeking answers in the dark night to manage the chaos of evacuation, obtain medical help for the victims, and eventually oversee the removal and disposal of bodies. . Poor communications (less than 10,000 telephones for 900,000 residents at the time) hampered the discovery of what was affecting the multitudes.

A plant operator spoke. He told how workers prided themselves working at the plant. However, change was underway, driven by Union Carbide's decision to close its Bhopal operations. Pressure to eliminate costs resulted in personnel layoffs, and decisions mentioned above compromised what could have been a safely run plant. Other speakers discussed the long-term health effects, and epidemiology studies and monitoring of the long term health impacts of the disaster have unexpectedly ceased. Finally, there were many papers related to process safety and how this accident influenced process safety practice across the world.

2. The site 20 years later

Our most astonishing discovery was the current condition of the Bhopal plant site. As one approaches, it looks like a jungle. Plants and trees have taken over (Fig. 6). Tank 610, the tank that over pressured and released the MIC, was removed from its underground vault, and is now above ground and totally surrounded by brush and overgrowth. Even more astonishing, sadly, bags of chemicals have been left behind, as shown in Figure 7. For 20 years! Fig. 8. is a photograph very near the filter area where a water washing cycle was underway the night of the accident. We were able to identify the gate valve that fed the process vent header located above in the pipe rack. Its stem indicated full closure, although this provides no evidence of its condition more than 20 years earlier during the incident. Fig. 9 is a photograph of the top entry to the concrete vault containing Tank 611, an identical storage tank to 610. Much of the piping is in place, undisturbed after 20 years. The rupture disk tag is still readable, and somewhat hidden, the spring relief valve that leads to the relief vent system lines. In studying the piping up close, we conclude that it is quite sophisticated. If sabotage was committed, the person who did it had to have intimate knowledge of piping into and out of the tank. Further, they had to have identified exactly how to remove a pressure indicator, and attached a quick disconnect hose connection, then after the event remove this quick disconnect hose connection (the condition it was reported to have been found by an eye witness). Fig. 10 shows the scrubber system. Manufactured of stainless steel, it is in reasonably good condition after more than 20 years. This plant had state-of-the-art equipment in place. Some motors appear as if they could operate today; simply flip the switch. Pumps, however, do show signs of corrosion after sitting in the elements for 20 years. Fig. 11 is a photograph of the flare system. This flare system went out service several weeks earlier due to a corroded pipe replacement project [14]. Little priority was placed on repairing it because the plant at the time was not manufacturing MIC. Fig. 12 shows the control room. By early 1980's standards, this was a typical control room with state-of-the-art equipment. Much of the paper that litters the floor are the remains of operating instructions and safe work permits. Its location from the plant was about 100 m to the West, well isolated from the process area. Fig. 13 made a sobering tour somber. We heard complaints from the local engineers who served as our hosts that mercury was contaminating the ground. Initially, we thought this was an exaggeration. Regrettably, as Fig. 13 shows, mercury droplets are quite prevalent near certain units. Fig. 14 shows a tank that has corroded completely, unknown contents lying below on the ground. Disturbing.

Such surface pollution is thought to have contaminated groundwater and rendered the drinking water in Bhopal hazardous. It is important for us to learn that when environmental activists speak of the deaths caused by the Bhopal Plant, they regard the MIC release as minor relative to the long-term environmental effects.

Fig. 6. Twenty years later, the flora covers Tank 610 which has been removed from the earthen mound.

Fig. 7. Former Plant operator T. R. Chauhan with bags of chemicals left behind in the background.

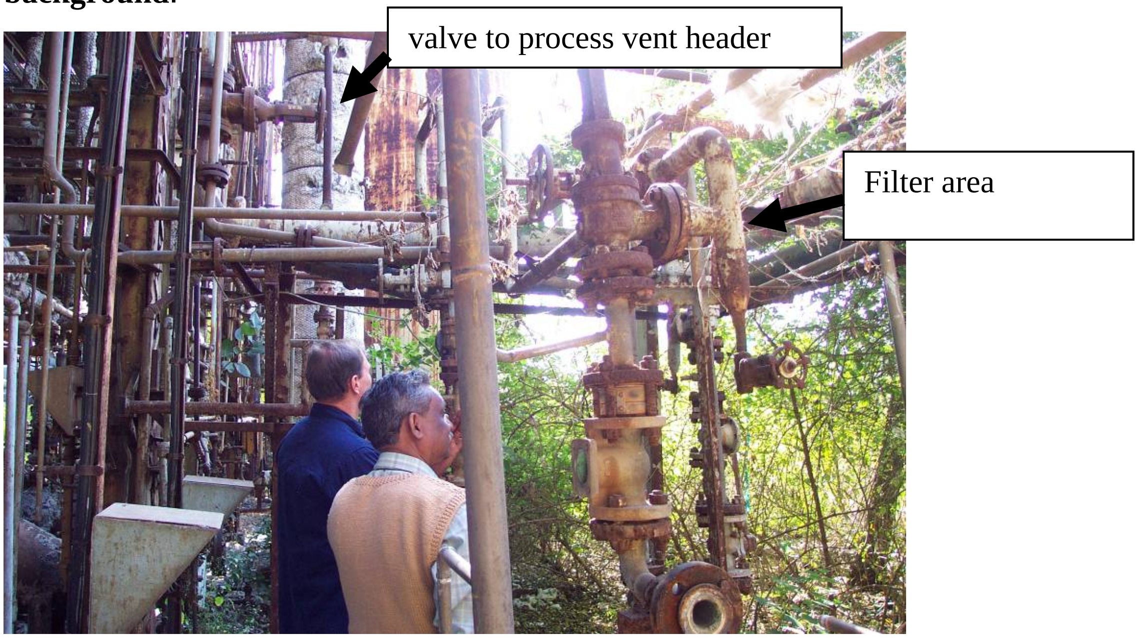

Fig. 8. Photograph near the filter area. Some of the critical components are identified in the photograph.

Fig. 9. Photograph of Tank 611 entry piping. Rupture disk is in center, spring relief valve is behind flora that has grown in over the years.

Fig. 10. Photograph of the scrubber system.

Fig. 11. Photograph of the disabled flare tower.

Fig. 12. Photograph of the control room 20 years later.

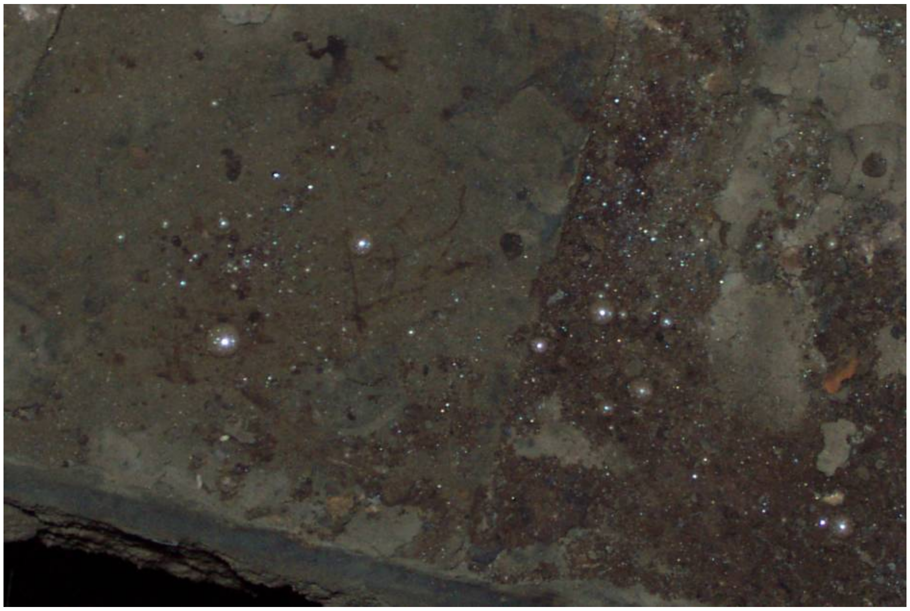

Fig. 13. Mercury droplets spotted on tour.

Fig. 14. Corroded tank with unknown contents lying below.

3. Discussion

The Bhopal disaster began long before the actual event, and its effects continue today, twenty-one years later. Although many of the early investigation efforts were directed to the initiating event – improper line blinding during filter washing, or intentional contamination by attachment of a water hose – it is clear today that the initiating event is basically irrelevant.

Clues to this accident were available in the days and months before it happened, and from the perspective of our experience twenty-one years later, perhaps even years before. If even one of the basic protections, i.e. the refrigeration system, the scrubber, the flare, the pressure gauge, the water curtain, and community emergency procedures, had been in place and functioning properly, many, many lives could have been saved. If communications between the plant and corporate management had been stronger – and perhaps given the state of communication technology in 1984, communications were as strong as they could have been – local management may have had better information and support and therefore not have made flawed decisions about fundamental safety principles. Likewise, corporate management would have had the opportunity to hasten the already-planned shutdown of the plant.

Roots of this accident extend even further back, well before the involvement of Union Carbide's manufacturing and safety personnel. Optimistic market-size expectations led to an oversized plant – and therefore MIC storage capacity oversized by a factor of three. Failure of state and local government to control the shantytown growth near the plant meant a considerably larger impacted population unable to shelter in place.

The consequences of Bhopal extend well beyond December 3, 1984 and the days immediately following. Thousands of people injured that day continue to suffer from symptoms caused by exposure to MIC, including respiratory distress. And, because Union Carbide was banished so abruptly from the site, the chemicals remaining on site were never properly removed, leading to significant environmental and health impacts, including a large number of stillbirths, which continue to this day.

Union Carbide paid an unprecedented large settlement to the Indian government and suffered other significant business and market losses in the years following 1984. Forced to sell of business after business in order to maintain its core operation, Union Carbide was eventually sold to The Dow Chemical Company in 1999, marking the sad end of a chemical industry pioneer.

Serious accidents are not common, so it is easy to fall into the mindset that they cannot happen. This is a common human failing, and it explains many risky behaviors from driving too fast on the highway to failure to maintain critical safety systems in a chemical plant. Bhopal clearly disproves this. In no circumstances does "unlikely" mean "impossible," and some possible consequences are clearly so significant that "unlikely" still leaves one with unacceptable risk that must be addressed more aggressively.

If there is a silver lining to this dark cloud, Bhopal has lead to improved process safety practices, through leading companies, through AIChE's Safety and Health Division and Center for Chemical Process Safety, and through many other organizations around the world. Fundamental principles such as Management of Change, Mechanical Integrity, Hazard Analysis, and Layers of Protection are now in the toolbox of most practicing chemical engineers around the world. It would be a stretch to say that an accident like Bhopal could never happen today, but as we work together to build a global culture of process safety, the use of the process safety tools – and the strength of process safety practices – will help prevent future Bhopals.

Finally, to keep our industry moving forward on this course and to prevent future tragedies like Bhopal, we as chemical engineers must all commit to never forgetting what happened on December 3, 1984. It is distressing how many chemical engineering students have never heard of Bhopal – we must be sure that this is one of their very first engineering lessons.

4.Conclusions

1. Every business decision has safety consequences.
2. A negative safety outcome is a negative business outcome.
3. In order to do the right thing, politics and the local community must be assessed, understood, and protected.

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