The Bhopal Incident: Implications for Developing Countries

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SUMMARY

The author summarizes the events of the Bhopal disaster as they are currently known, and draws a number of very important conclusions regarding safety procedures. These have implications for all developing countries.

INTRODUCTION

The accidental release of Methylisocyanate (MIC) from a pesticide manufacturing factory on the night of 2nd/3rd December 1984 caused the death of about 2500 persons and affected about 100000 people (20% of the total population) at Bhopal, India. Some newspapers reported that 5000 to 8000 people died as a consequence of this accident. A number of implications for decision makers from developing countries arise from the accident, since it is an example of how a large number of socio-economic issues interacted with factory management systems and caused death and agony to a large number of people. This paper is an attempt to analyze the implications of the Bhopal accident. Developed countries, in attempting to transfer technology to less industrial countries, should both implement and enforce safety regulations and realize the importance of additional safety parameters to take into account the socio-technical environments of the developing countries.

NORMAL ACCIDENTS

Normal accidents can be characterized using two parameters, namely, interactiveness (complexity of the systems, which makes it difficult for the operators to make correct decisions at the time of emergency) and coupling (linkage between the subsystems, which makes it difficult to separate subunits during times of accidents). Figure 1 gives a classification of normal accidents based on these two criteria. As can be seen from the figure chemical plants have a high degree of interactiveness (Perrow, 1984), which baffles operators during exigencies; and strong coupling, which makes it difficult to separate the subunits when hazards occur. The Bhopal incident is an accident causing a major catastrophe because of the high toxicity of methylisocyanate and the failure of the safety systems which were incorporated in the plant for preventing the release of MIC. Given this background the Bhopal incident can be analyzed. Before analyzing the issues, a brief description of MIC and its toxicity is relevant.

METHYLISOCYANATE

Methylisocyanate has a formula CH_3-N=C=O, it is a colourless liquid with a powerful odour and is a methyl ester of isocyanic acid (H-N=C=O). The boiling point is 39°C at normal atmospheric pressure and it has a flash point of 7°C below zero. MIC is highly volatile, but stable under dry conditions. The vapour is 2.2 times denser than air. It is highly reactive and gives rise to a number of products ranging from simple carbamates to polyurethane formulations such as foams, adhesives and plastics. The chemistry of MIC is briefly given as an Appendix.

Methylisocyanate is biologically very active. Even in very small amounts it causes irritation of the eyes. When inhaled it reacts vigorously with fluids in the lungs. Since the gases produced are heavy, oxygen is expelled from lungs causing choking and death. Injury to humans from MIC occurs through two routes namely; i) the accidental absorption in massive doses, resulting in acute toxicity, or ii) through prolonged exposure to low concentrations of the vapour in air, leading to chronic toxicity or sensitization of the subjects (Kumar and Mukherjee, 1985).

Data on acute toxicity of MIC in terms of lethal dose (LD_{50}) (i.e. dosage required to kill 50 percent of the population under trials) for isocyanates and related compounds are given in Table 1. The threshold limit value (TLV) in air for MIC is 0.02 ppm as per the manual (Ramasehan, 1984) given by Union Carbide India at Bhopal (Table 2). A comparison of toxicity data with other materials shows (Table 2) the extreme toxicity of MIC. This is mainly due to its high volatility, high reactivity, low solubility and high penetration. Other TLV tables available also report (Sax, 1984) that the maximum allowable concentration of MIC in air is 0.02 ppm or 0.05 mg/m^3. MIC reacts with almost all vital bio-substances in the body such as

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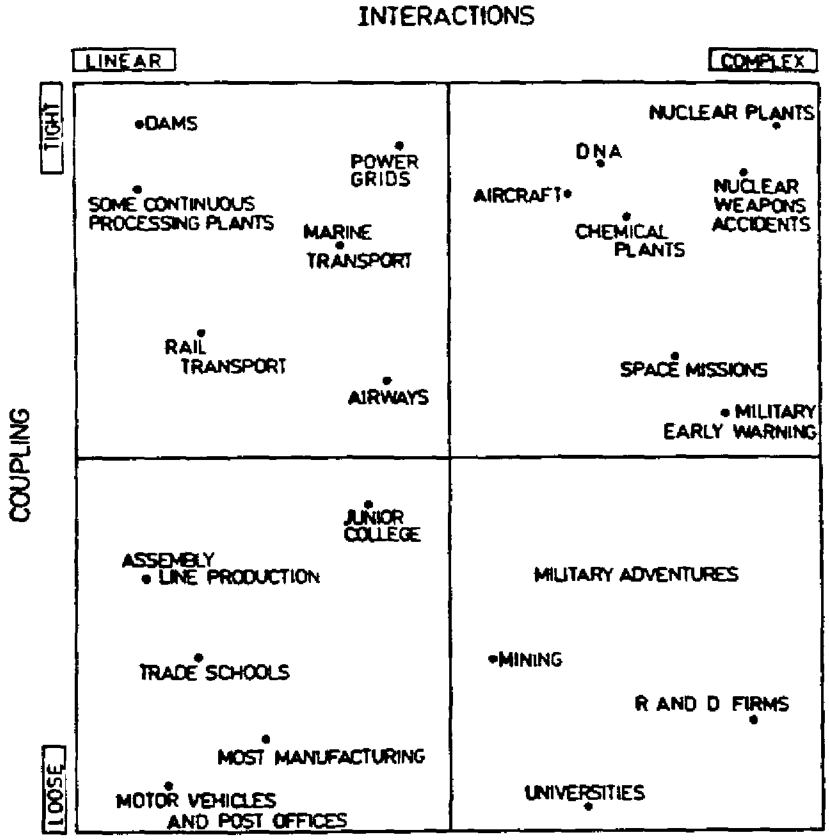


Fig. 1. Normal accidents. *Source:* Perrow (1984)

amino acids, ribonuclease, chymotrypsin, haemoglobin, sensitive enzymes, and in many cases inactivates them. Because of this, toxic effects of MIC can be long-lasting and irreversible. It has been reported that even 50 days after the accident the concentration of carboxyhaemoglobin and methaemoglobin has not fallen in some of the patients exposed to MIC at Bhopal (Srinivasan, 1985).

MIC polyermizes in the presence of external substances, and also reacts with water. To inhibit the polyermization of MIC, phosgene is added while storing. The possible cause of the Bhopal accident (as reported by the Head of the Indian team of scientists who conducted the neutralization of the remaining MIC in the third tank after the accident, on the direction of Government of India) was the entry of water into the MIC tank (Varadarajan, 1985). The MIC pipes were being washed just prior to the accidental release of MIC on the 2nd December 1984. When MIC polymerizes a large quantity of heat is released. Polymerization of MIC is 200 times faster at 25°C than at zero°C and hence refrigeration is a prime safety precaution. The polymerization of MIC is catalyzed by hydrochloric acid. The accidental entry of water into the MIC tank would have caused mixing with phosgene. Phosgene reacts with water (See Appendix) producing hydrochloric acid. The entry of water thus resulted, in the partial removal of the inhibitor (phosgene), and the production of the catalyst (hydrochloric acid). This seems to be the cause of the Bhopal accident. Before examining the various issues the safety precautions at the plant should be examined.

SAFETY PRECAUTIONS

Chemicals may create hazards in any one of the production phases, such as storage, transport, the reaction, or storage of the product. MIC is a highly toxic substance and hence provision has to be made for its safe use in all of these phases. Because of the acute toxicity of MIC the following specific precautions have to be taken (Ayres, 1985; Khandekar and Dubey, 1984; Rout, 1985).

1. Bulk storage of liquid MIC should be made only in underground tanks made of stainless steel (SS 344 and 316) encased in concrete.
2. The tank size should be at least double the maximum volume to be stored, or alternatively a standby tank should be made available.
3. An inert atmosphere of nitrogen at 2–10 psi pressure should be provided.
4. Maximum storage time of MIC should be limited to 12 months.

TABLE 1.
Toxicity of Isocyanate and Related Compounds

Name	LD_{50} (mg/kg)	Administration
Carbondisulphide	300–400	Dermal
Cyanamide	125	Oral to rat
Sodium isocyanate	310	Intraperitoneal
Potassium isocyanate	320	Intraperitoneal
Methylisocyanate	2 ppm in air	Inhalation – man
	5 ppm	Inhalation – rat
	71 ppm	Oral – rat
	220 ppm	Percutaneous – rabbit
	120 ppm	Oral
Toluene diisocyanate	0.5ppm	Inhalation – man

LD_{50} = Dosage required to kill 50 percent of population under trial.
Source: Kumar and Mukherjee (1985); Sax (1984)

TABLE 2.
Hazard rating and TLV of MIC as given by UCI

	Hazard rating on health (4 = highly toxic)	Fire hazard (4 = highly inflammable)	Stability hazard (4 = very unstable)	TLV in PPM
Carbonmonoxide	4	4	1	50
Chloroform	3	0	1	25
Methylisocyanate	4	4	3	0.02
Phosgene	4	0	2	0.01
Monomethylamine	4	4	1	10

TLV = Threshold limit value
Hazard rating on a 0–4 scale. 0 indicate low hazard.
Source: Ramaseshan (1984)

5. MIC tanks should be refrigerated and a temperature close to 0°C (in any case, below 15°C) should be maintained.
6. Regular scheduled inspection and cleaning of valves and piping is essential.
7. Protective suits and air breathing equipment should be provided for personnel engaged in sampling or testing.
8. A vent gas scrubber, capable of neutralizing about 8 tonnes of MIC per hour should be provided.
9. A 'water curtain' 12 to 15 meters high capable of dissolving any escaping MIC not neutralized by the scrubber or flare is required.
10. A siren capable of alerting the surrounding community in the event of an uncontrolled leak should be provided.

WHAT HAPPENED AT BHOPAL?

Union Carbide India (UCI) started its operations in 1969. The production of carbaryl pesticides were planned from 1977. Because of some design problems the actual production of the carbaryl pesticide commenced in 1979. The demand, however, was less than anticipated and the company failed to make a profit in the operation. Because of this lack of profit, there was a resistance to make additional investments for safety or modernization of instrumentation. Any safety lacunae have to be viewed against this background. When the MIC plant was set up one of the conditions stipulated by the Union Carbide Corporation of USA (UCC) was that the plant should have its own trained superintendent. In order to prune expenses, the trained Superintendent was transferred to Madras, and the MIC plant was put under another Superintendent giving him an additional responsibility along with other units (Kulkarni, 1985). This may have been a further reason for neglecting safety.

Complete information is not available (and is not likely to be available until the enquiry is completed) on what happened at Bhopal on the night of 2nd/3rd December, but the description given here is an account derived from all published and reliable reports on the Bhopal incident. There are three MIC tanks (Fig. 2) at the Bhopal plant (tank numbers 610, 611 and 619). At about 11.00 pm the pressure in the MIC tank 610 was found to rise rapidly from the normal 3 psi, to 10 psi. Immediately prior to this, the MIC pipes had been cleaned using hoses without proper precautions. Workers who pressurized the tank 611 to move the MIC into the manufacturing system, did not consider the pressure rise in tank 610 a major cause for concern. The operating staff started feeling irritation in the eyes. Tiny leaks are normal and hence they reported the leak only when the irritation became prolonged. By 12.00 midnight the operators had reported the leak to the Production Assistant. The MIC control room also reported that the pressure in the tank 610 was

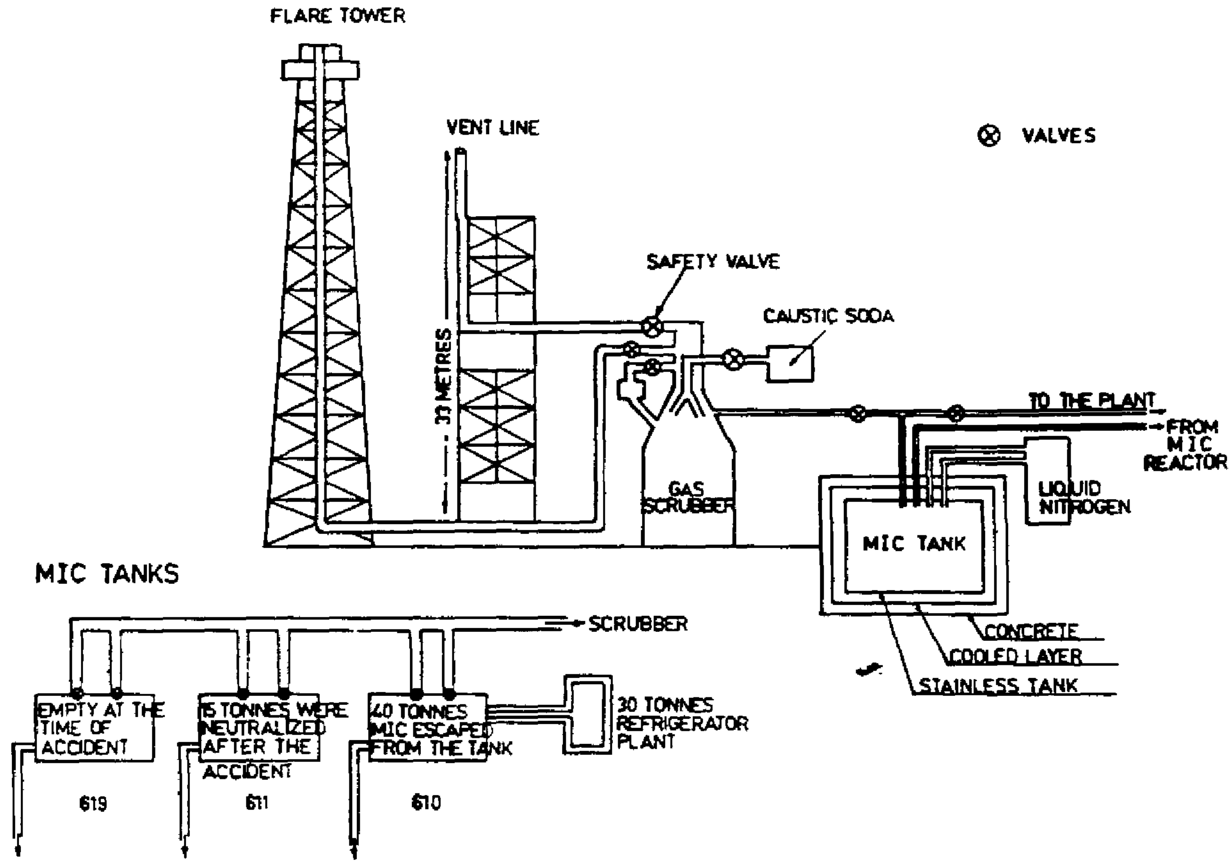
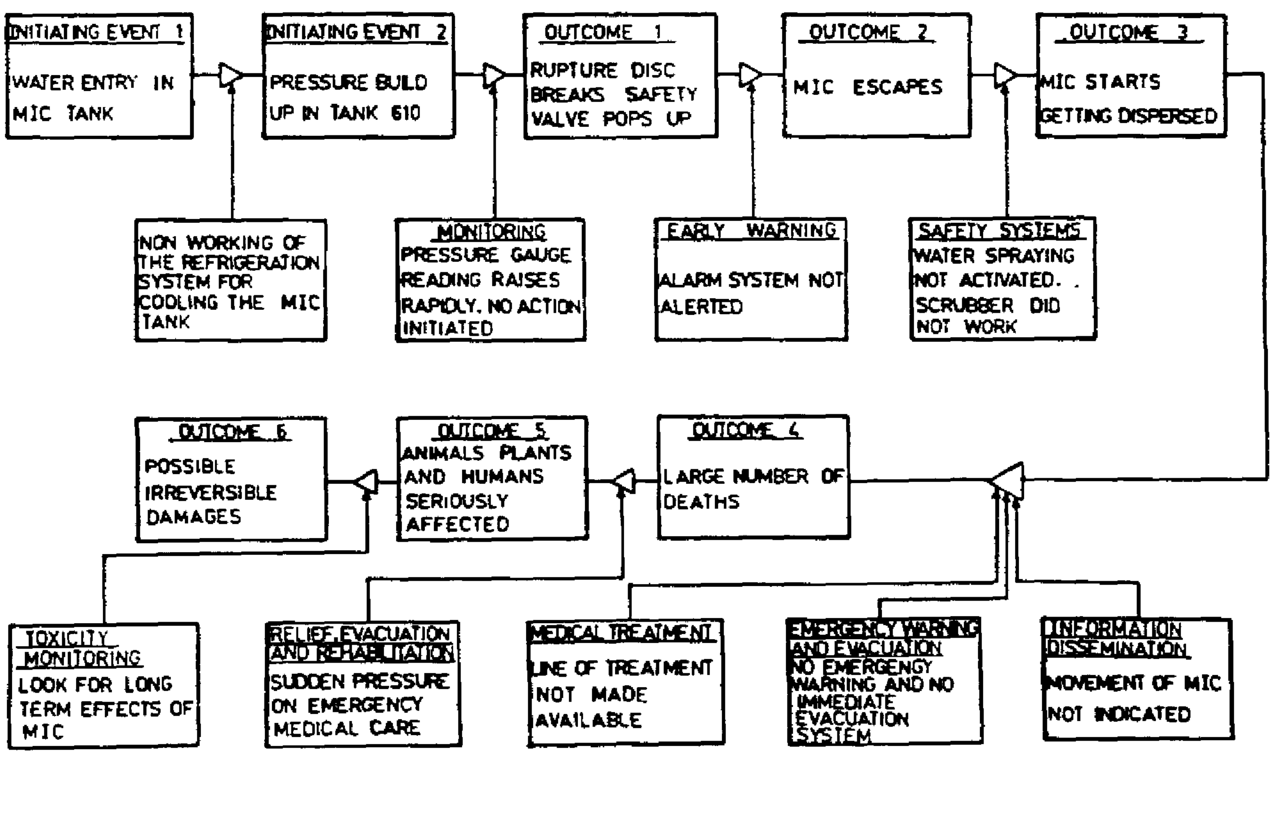


Fig. 2. The Bhopal pesticide plant. *Source:* Subramaniam (1985)



unusually high. A few minutes after midnight, the Production Assistant checked tank 610 and found that the rupture disc, set to release gas into the vent if the pressure exceeds 40 psi had burst, and the safety valve had popped. MIC was found escaping through the 33 meter high vent tube.

The public was alerted at 1.00 am by means of the siren, but after some time the siren was switched off. It was alerted again (at full blast), only at 2.00 am. It was reported that people tried to contact the UCI plant, but could not contact the officers of the plant because the telephones were not working. By then, in certain parts of the city and in the squatter settlements around the factory, people had started dying. Meanwhile, the police had received news of the MIC leak, but when they called up the factory they failed to receive any confirmation. The manager of the plant was told about the incident at 1.45 am by the Additional District Magistrate of the city. The walkie-talkie system at the factory was never used. The MIC leak was finally plugged at 3.00 am by which time most of the 40 tonnes of MIC in tank 610 had escaped. About 100000 people fled from their homes. Though the press has reported that about 5000 persons died at Bhopal, the government sources confirmed that only 1347 deaths were counted after the accident. An emergency coordination meeting of the government officials was not organized until 4th December, 1984. There was a severe shortage of hospital beds, and doctors. About 790 buffaloes, 270 cows, 483 goats, 90 dogs, and 23 horses died on the first day of the accident. The doctors were not fully aware of the proper courses of treatment. Confronted with a large flow of patients, and an unknown combination of symptoms whose root cause was not known, doctors in Bhopal, in a quandary, resorted to mainly *ad hoc* treatments (Ramaseshan, 1984). It has been reported that UCC and UCI did not divulge the proper line of treatment (Ramaseshan, 1985). Unlike that of phosgene poisoning, ventilation alone does not help in the case of MIC poisoning, since there is a reaction with enzymes in the blood.

The safety systems planned at Bhopal did not work when they were badly needed, and many of the precautions were completely neglected. Figure 2 gives a systematic sketch of the UCI plant, and where the accident occurred (Subramaniam, 1985).

The major safety failures were:

1. The refrigeration system (30 tonnes capacity) for the MIC tanks to maintain the temperature close to 0°C was not operative, even though the safety manual stipulated its function.
2. The scrubber meant for neutralizing the escaping MIC did not have enough caustic soda present to neutralize the gas. The system was designed to neutralize 88 kg/hr of MIC, but the accidental release of MIC was of the order of 20000 kg/hr (Bidwai, 1984).
3. The flare tower for igniting the escaping gases also was not operational, the connecting tubes having been dismantled for maintenance.
4. One storage tank (619) was kept empty for evacuating MIC from the other tanks in the event of a leak. Published reports say that operators panicked, and no emergency operations programme was implemented so that tank 619 was not used.
5. The sirens were not operated until 1.00 am although the leak occurred before 11.30 pm. Nobody from the factory reported the accident to the police.

The failure of the safety systems, along with the lacunae in hazard management procedures, made the Bhopal incident a severe accident in terms of loss and dislocation of life, and other possible long term adverse effects. The flow chart given in Figure 3 summarizes the major events and outcomes. At every stage a possible action could have reduced the negative effects.

BASIC ISSUES

The basic issues arising out of the accidental release of MIC has been given in Table 3 starting from the technology choice decision, to the final handling of the impact of the release, and the role of government.

1. Choice of Technology

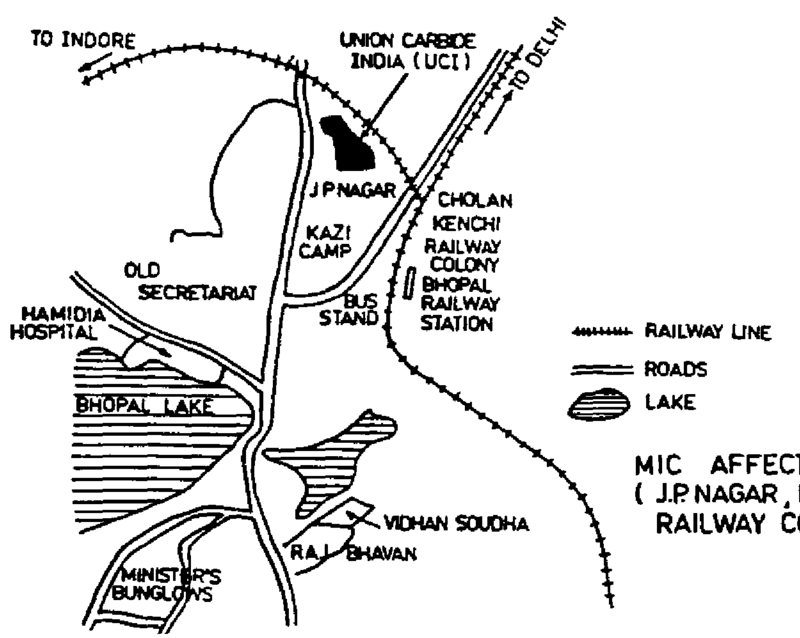
There are alternative carbaryl production technologies (Carbaryl is made by reacting MIC with alpha Napthol and is a Carbamic acid ester) (used by Bayer) which involve no storage of MIC. In the case of pesticides and other toxic materials, governmental decision making systems for technology choice decisions should examine the various alternative routes. In India, foreign collaboration proposals, as Bhopal, do not appear to be fully evaluated in terms of alternative options (Reddy, 1981). The government should have insisted on enforcing stringent safety measures at the time of giving license for the use of MIC for manufacturing pesticides, particularly, in a country with low levels of literacy.

2. Siting of the Industry

The pesticides factory (Union Carbide India), was established in 1969 close to Bhopal (Fig. 4.). The plant was built particularly close to the highly populated areas. As can be seen from Figure 4, the Railway Station, the Bus Station, the Old Secretariat and Hospitals are all close to UCI. The lake which supplies drinking water to Bhopal city is also close to the UCI plant. Because of the position of this lake, there were doubts as to whether the public water supply was free of toxicity immediately after the accident. Bhopal was one of the cities in India which experienced a growth rate of population of about 75 percent during the

TABLE 3.
Basic Issues or Lacunae

STEP	LACUNAE/ISSUE
Choice of Technology	1. Alternative pesticide production technologies not evaluated or pursued 2. Considerations of major safety precautions
Siting of Industry	1. Siting close to a city 2. Allowing the squatter settlements to come up close to the factory 3. Zoning of the country in terms of locating toxic or hazardous units
Design of the plant	1. Design of the plant for maximum safety 2. Incorporate safety designs used elsewhere
Information dissemination	1. Information on toxicity of MIC not known to people living close by 2. Antidote for MIC and mode of treatment for MIC poisoning not made available
O & M Practices	1. Installing relevant and latest safety precautions 2. Safety systems poorly maintained 3. No accident or emergency planning, or mock drills 4. No warning system 5. Delay in informing public 6. No emergency communication systems 7. No follow-up based on earlier accidents
Management of hazards	1. Poor early warning systems. 2. Poor emergency preparedness 3. Slow evacuation procedures 4. Relief/rehabilitation 5. Detoxification
Regulatory procedures	1. No stringent systems for toxic units 2. No procedures for managing toxic substances 3. Poor reporting of toxic substances stock 4. Poor monitoring of safety regulations 5. No environmental audit 6. No follow up on earlier accidents by regulatory agencies
Role of Government	1. Poor awareness 2. Lack of institutional mechanisms for managing disasters 3. Lack of statutory regulations on toxic materials 4. Poor compliance on safety regulations 5. R & D for Biological pest control 6. Increasing the number of experts capable of handling toxicological problems



MIC AFFECTED AREAS OF BHOPAL
(J.P. NAGAR, KAZI CAMP, CHOLAN KENCHI, RAILWAY COLONY, BUS STAND)

period 1971–81. This unprecedented growth resulted in the mushrooming growth of squatter settlements. A large squatter settlement developed in the vicinity of the factory to support service employments such as canteens, coffee shops, etc. Allowing such squatter settlements (slums) to be built in the vicinity of the factory is a major issue for which the local government must accept responsibility. Most of the deaths occurred in these squatter settlements. Figure 4 indicates the areas affected by MIC release. The local government gave legal sanction for the illegal hutments in 1983.

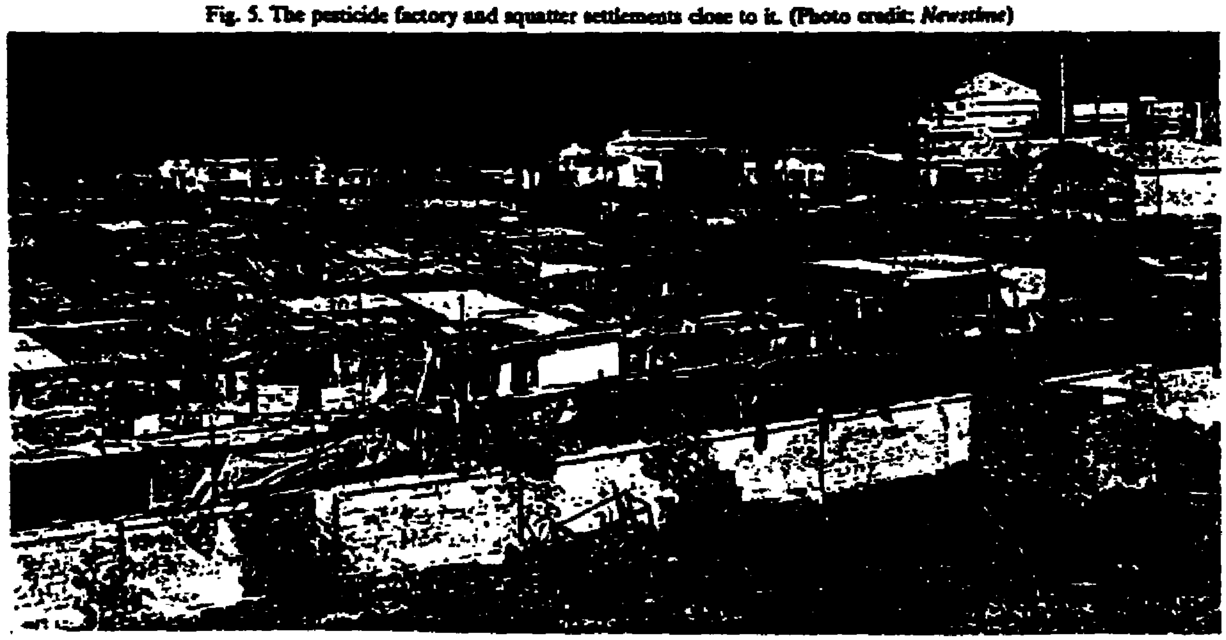
The siting of the pesticide plant in Bhopal in 1969, and permission for its expansion in production in 1979, were mainly due to the absence of zoning regulations in the country for locating potentially toxic units. Though a local administrator had raised the issue of allowing UCI to produce carbaryl pesticide close to Bhopal, top government officials did not give any serious thought to this objection, and UCI was allowed to expand (Awasthi, 1985).

3. Design of the Plant

The design of the plant did not take sufficient consideration of the severe toxicity of MIC. The toxicity, as given by the UCI manual, is given in Table 2 (Ramaseshan, 1984). The factor of safety required should probably be higher for a plant to be operated in India, for the operators may not be as highly skilled as those appointed at the West Virginian plant of the Union Carbide Corporation (UCC). The major problems related to the safety of the Bhopal plant design are:

1. The water curtains, if operated together, can only reach a height of 10 to 15 meters, whereas the MIC escaped through an escape vent located at 33 meters in height.
2. Even at maximum capacity, the vent scrubber would not have been sufficient to neutralize the escaping MIC. It has been reported that the caustic in the scrubber is capable of neutralizing only 7 tonnes, whereas a tank contains 40 tonnes of MIC (Ayres, 1985). When plants are designed, the worst case scenario should be anticipated. The scrubber and storage should have matching capacities. This also poses the question as to whether the storage of such large quantities of MIC should have been allowed.
3. The safety systems should automatically switch on in the event of a leak, instead of relying on manual switching. The low levels of suitable instrumentation, the lack of provision of duplicate instrumentation, and failures in the monitoring systems, have each been major issues in the disaster.
4. The pressure monitoring systems for the toxic materials should have been duplicated. The MIC pressure gauge at the control panel was not working when the accident occurred.
5. UCC should have incorporated in the design an additional safety system used in Bayer plants (Ramaseshan, 1984a). In the Bayer plants, MIC, when it escapes, is vented into a nearby area capable of flooding with water. Considering the fact that the total investment for the Bhopal plant was Rs.25 million (US $ 2 million), this additional safety system would not have added considerably to the overall plant cost.
6. An additional provision for flaring MIC from the top of the vent scrubber, in the event of unneutralized gas escapes from the scrubber, should have been established.

Fig. 5. The pesticide factory and squatter settlements close to it. (Photo credit: *Newstime*)



In the case of design of plants dealing with toxic substances, license applicants should not only analyze single failure accidents, but also analyze what happens when systems fail independently of each other (Gorinson, 1982).

4. Information Dissemination

The information that MIC is a toxic material should have been made available to the public staying in the vicinity of the plant, the public health authorities, and government agencies. The possible precautions which should necessarily be taken in the event of a leak should have been publicized. Mere inhalation through a moist towel would have made MIC inactive (Varadarajan, 1985). If this information had been disseminated immediately after the accident a number of lives could have been saved. The fact that deaths occurred even on the second night (3rd/4th December) when the temperature again dropped, is mainly due to poor mass media response and poor dissemination of meterological information on the direction of wind movement. Either the company, or the government, should have used television, radio and other means for propagating information and simple safety measures.

Even within the plant, the operators were not aware of the grave consequences of the leak when it really happened. It has been reported that one operator who identified the leak, first suggested at about 11.00 pm that the plant should be immediately closed, but his advice was not accepted (Awasthi, 1985).

When a highly toxic material is being stored close to a large city, as at Bhopal, the local doctors should at least have been given advice on the possible course of action in the event of a leak. Doctors should also have been given the information on how to treat the earlier effected gas victims. There have been reports that neither Union Carbide India nor Government agencies did this (Ramaseshan, 1985). In fact, there has been some secrecy on the reports of the deaths of the gas victims (Srinivasan, 1985). Even two months after the incident, doctors have been keeping the toxicological information as a closely guarded secret. Lack of dissemination of information, and too much secrecy, have both impaired the treatment procedures. Most of the doctors resorted only to symptomatic treatment in the absence of proper advice. The delay in not informing the public authorities immediately about the release of the MIC was another major communication failure. No plans for emergency procedures had been prepared. The doctors knew about the accident only when the patients started arriving at the hospital.

5. Operations and Maintenance Systems

Serious operational and maintenance failures were major causes of the Bhopal accident. Had the plant been properly operated and maintained the whole were amplified by poor maintenance factors. A US team had identified a number of serious safety problems when they visited the Bhopal plant in 1982 and had submitted a report to UCC, but it is not known what action was initiated by UCI with respect to this. The safety problems identified were the following (Awasthi, 1985).

1. Manual control for the filling of the MIC tank with no instrumentation backup created a possibility of accidental overfilling.
2. The pressure gauge of the phosgene tank was out of order, and showed no pressure, even though the tank was in service.
3. There was no fixed water spray system for fire protection or vapour dispersion in the MIC operation area.
4. There were several conditions in the operation of the unit that presented a serious potential for sizeable releases of toxic materials.
5. Filter cleaning operations of the MIC pipes were performed without slip blinding process lines. Leaking valves could create serious exposures during the cleaning operations.
6. Long pressure gauge inlet lines, without vents, could have resulted in the release of MIC when the gauges were replaced, due to the inability to evacuate them safely.

UCC had forwarded their findings to Union Carbide India, but no serious corrective measures seem to have been incorporated. If UCC had strictly instructed UCI on safety, the accident would have been prevented.

No recent relevant safety precautions have been installed at the Bhopal plant and the following precautions might have been expected:

1. New monitoring systems should have been installed, as for instance, sensors for, pressures, temperatures, volumes, and flow, and gas leak detectors. It has been reported that no gas leak detectors were available at UCI (Ayres, 1985).
2. An automatic warning system that would have been triggered by the rapid rise of pressures in the MIC tank would have helped the operators to switch on safety systems without panicking (Ayres, 1985).
3. The scrubber should have had an automatic switching mechanism rather than manual operation (Ayres, 1985).
4. A safety interlock arrangement should have been devised to prevent the operation of the plant if the scrubber and/or refrigeration unit were disconnected (Ayres, 1985).
5. There should have been an automatic water spraying system linked to gas leak detection.
6. There were only two breathing masks available within the MIC plant (Ramaseshan, 1984) when the MIC release occurred, but there should have been more.

Fig. 6. Dead bodies kept for identification. (Photo credit: *Newstime*)

prescribed in the maintenance schedule in all cases where toxic substances (MIC, Phosgene) are being handled.

8. Detailed safety analysis exercises should be worked out, and a flooding arrangement similar to those used in Bayer plants should have been used.

The UCI unit at Bhopal was not making a profit, and as a consequence of this i) the number of operators for maintenance was reduced, ii) no new safety equipment was installed, and iii) safety and safety precautions were neglected. Even though six accidents had occurred in UCI since 1978, neither the top managers nor the parent company (UCC) intervened to improve the safety, despite the high toxicity of MIC.

No major emergency exercises or manuals had been prepared at the plant. The requirement for these appears to have been overlooked. Lack of an emergency plan made the operators panic when the leak was detected. This might well have been the reason why the valve (Fig. 2) between 611 and 619 (619 was kept empty as a relief tank) was not operated. Even within the factory no emergency drills had been rehearsed and the gas release, therefore, resulted in a panic response.

Finally, the sirens for warning the public were not operated until 1.00 am. Some people came in the direction of the plant, thinking that the siren was a fire alarm rather than a danger warning (Khandekar and Dubey, 1984). This represents nothing more than a failure in communication. Had enough warning been given to the public before the event about the nature of siren warnings many more persons would have left the location appreciative of the impending danger.

6. *Management of Hazards*

In India, although natural hazards are of frequent occurrence, industrial accidents are not, and hence an institutionalized hazard management system has not been developed. There was a long delay in alerting the public at Bhopal. The public should have been warned using the mass media and mobile warning systems. Emergency procedures were very poor. Large scale evacuation of people using buses would have reduced the magnitude of the tragedy. The sudden pressures on the hospital system were also a problem. The largest government run hospital (Hamidia) has a capacity of 750 beds; on 3rd December, 1984 it had to treat 12000 patients suffering from very serious conditions, and on 4th December, it had to deal with 55000 victims affected by the leakage (Kulkarni, 1985). For all major locations, hazard management plans should be prepared and these should identify the officials responsible for early warning arrangements, emergency preparedness, evacuation procedures, relief, and rehabilitation and detoxification of the contaminated area. US firms dealing with hazardous substances are not granted operating licenses until the company prepares an emergency response plan and gets it reviewed and approved by a federal agency responsible for emergency management (Gorinson, 1982; Zajic and Himmelman, 1978). In Bhopal, the State Government initiated large scale emergency operations only on 4th December after a delay of 40 hours. The themes of a hazard management plan should involve i) prevention of hazards, ii) prevention of hazard consequences once the events have occurred and iii) mitigation of the hazard consequences once these have occurred (Hohenemser, Kasperson and Kates, 1982).

The released MIC initially spread on the city side (south side, in Fig. 4), but some of the affected people fled in the direction of MIC cloud movement, towards the city. Proper wind direction and velocity information was not provided. The movement of the MIC gas towards the southern parts of the city ceased during the day of 3rd December, but again it moved towards the city the following (3rd/4th December) night. The wind direction during a major part of the year is normally away from the city, towards the north; inversions combined with very mild winds, can, however, reverse the wind to impose a southerly direction. Though in probability terms gas movement towards the south should have been negligible, proper assessment of the worst case scenarios should have been made at the time of siting the plant.

7. Regulatory Processes

A major concern in India regarding regulatory processes is the absence of stringent regulations for toxic units. Existing factories treat toxic and non-toxic plants in the same way. In USA, the Toxic Substances Control Act (Miller, 1983) details three major provisions, and these are stipulated by government agencies in the case of corporations dealing with toxic substances. They are that:

— companies should routinely test chemical products for toxicological effects and submit health and safety studies,
— chemical manufacturers should have the responsibility of reporting any indication of adverse effects,
— the presidents and other top officials have the responsibility for ensuring that adverse information is reported.

French and EEC legislation (Parameggiani, 1983) provide for compensation for ailments caused in industrial environments by isocynates.

Statutory reporting of storage of toxic materials should be introduced in India, along with records of suitable safety precautions and antidotes or preventive measures. Use of toxic substances for which the antidotes are not known should be rigidly controlled. Government inspections for safety of toxic materials need to be more stringent. Such inspections should relate to a classification of toxic substances in terms of lethality. A system similar to the US Environmental audit (Vanderver, 1983) must be made statutory for industries dealing with toxic materials.

It has been reported that five accidents occurred in (Awasthi, 1983). On 26th December, 1981 one person died. In February 1982, about 25 workers were affected and hospitalized, and on 5th October, 1982 there was a serious accident. In 1983, there were two further accidents. The existing Indian Factories Act does not deal with toxic materials or hazardous materials as a separate category (Rao, 1984). Accidents resulting in death merely have to be notified to the Inspector of Factories. No provision has been made for follow up action to improve safety. Although the Government had appointed committees to look into the accidents no corrective measures were initiated based on the feedback information. The incorporation of corrective measures should be made statutory. Table 4 gives the status of regulations regarding MIC release and its implications, in other countries and in India. This table shows the need in India for establishing new regulations and for better implementation of the existing regulations.

8. Role of the Government

The State Government of Madhya Pradesh should have been more responsive to the needs of the situation and the following issues emerge:

1. There has been insufficient awareness of the toxicity of MIC. Although there was a move to shift the unit to a new site in 1976, it was not seriously considered by the Government. When the question was raised in the state legislature the Minister concerned indicated that there would be no safety problems at UCI (Awasthi, 1985).
2. A number of press reports appeared in newspapers during September and October, 1982 and again in June 1984 about the toxicity of MIC and the lack of safety precautions at UCI, but the Government of Madhya Pradesh did not initiate any enquiry or actions (Khandekar and Dubey, 1984).
3. The lack of a disaster management plan or an emergency relief plan was partly because the senior politicians were away from the state capital and involved in the parliamentary elections. This suggests the need for having a decentralized disaster management plan for major cities. Major US companies dealing with hazardous materials have emergency plans approved by federal agencies (Zajic and Himmelman, 1978).
4. There was very poor compliance with safety regulations even though there had been six accidents in the plant since 1978 (five, subsequent to 1981). The number of operating personnel in the MIC plant had been reduced from 11 to 6, and in the MIC control room the number of operators had been reduced from two to one (Kulkarni, 1985).
5. The lack of statutory regulations on toxic materials, has already been detailed.
6. The Trade Union has shown little concern for the

TABLE 4.
Status of regulations in relationship to MIC release

Regulations	Developed Countries	Status in Indian in relationship to Bhopal Incident
1. Classification of toxic and hazardous substances	Classification based on degree of hazard and toxicity	No classification of toxic substances. Factories Act same for all substances
2. Toxic substances control act	Reporting of toxic substances	Pesticides Act exists, but does not cover items like MIC
3. MIC storage	No storage permitted in Germany and Netherlands	No specific law
4. Occupational Safety and Health	Catastrophic accidents (involving more than five persons) need a detailed analysis	No statutory procedure for improving safety based on information from previous accidents
5. Environmental audit	USEPA requires environmental audit for existing facilities, periodically	No specific law or requirement
6. EIA & siting of industries	EIA for major industries	Assessment necessary only for new industries while applying for industrial licenses
7. Zoning or urban development regulations	Zoning as a policy for locating industries	No specific zoning law or regulations
8. Emergency plan	In US, hazardous industries have to prepare Emergency Plans	No specific statutory requirements
9. Factories Act	Separate regulations for toxic materials	No distinction in the inspection and safety regulations for toxic and non-toxic substances

concerned about short term monetary issues than health hazards.

7. It was found that UCI had stored about 62 tonnes of MIC at Bhopal although the daily requirements were only 5 tonnes. The storage of large, unnecessary quantities of MIC was a major lapse in safety, and it should not have been permitted. In many countries, such as Germany and the Netherlands, storage of MIC is prohibited (Ramaseshan, 1984a). Storage regulations for toxic chemicals need reassessment.
8. Voluntary agencies and conservation lobbys could help more in educating the public and in improving the safety of such plants.
9. UCI's apparent lack of compliance with necessary safety regulations appears to have been neglected by the authorities responsible for the implementation of the Indian Factories Act. Since 1978, six serious mishaps have occurred in the factory and if the State Government had been careful enough to examine the causes of these accidents and subsequently suggest ways of improving safety, the final Bhopal incident would have been averted. Though accidents in factories in India have increased from 5 289 in the year 1962, to 18 563 (in 1984), the factories inspectorate has not been strengthened. For example, each Factory Inspector in Madhya Pradesh (responsible for the inspection) has to inspect 286 factories in a year (Mathai, 1985). Limited inspection of this nature is not effective.
10. It has been reported that MIC may cause

Fig. 7. Children were the worst affected. (Photo credit: *Newstime*)

irreversible and long term effects on the victims. About 100000 persons have probably been exposed to MIC. Regulations are to be made for the proper monitoring of the long term effects and for paying compensation to the victims. Two months after the accident some of the persons living close to J. P. Nagar continue to cough and wheeze, and complain of watering and burning eyes, they suffer from photophobia, loss of appetite, pains in the back and in the chest, swellings, breathlessness, cysts, rashes, excessive bleeding, and headaches and dizzy spells (Sharma, 1985).

11. The Government should seriously examine the alternatives to chemical pesticides such as biological pest control. More funds should be set aside for the provision of biological pest control methods, and research and development should be promoted. Although there is an Insecticides Act, passed in 1972, it needs to be reviewed in terms of voluntary reporting and systematic toxicological studies. It has been reported that even 50 days after the accident some of the subjects exposed to MIC have very high levels of carboxy haemoglobin and methaemoglobin (Srinivasan, 1985). Very little work has been reported on the toxicity of MIC to humans, and the Union Carbide Corporation exclusively held most of the information on MIC. The lack of publicity of the antidotes for MIC is a major act of negligence, although some books on occupational health have reported suitable treatment for MIC poisoning (Proctor and Hughes, 1978). Wide publicity of this information, using the public media, would have reduced the number of deaths. More stringent conditions should be stipulated for highly toxic substances in all cases where human toxicological effects are not known. Finally, experts capable of handling toxicological problems should be trained through proper technical training and research work. Since not many toxicology experts were available outside UCI, the Government had to depend on UCI personnel for the neutralization of the MIC which remained in tank 610 after the disaster.

Fig. 8. Animals were affected. (Photo credit: *Newstime*)

Fig. 9. Removing the dead animals from the roads. (Photo credit: *Newstime*)

TABLE 5.
Imperatives for Decision Makers

Agency	Decision	Imperative
A. TECHNOLOGY AND SITING DECISION		
1. Government	Technology Choice	Proper assessment of alternative technologies
2. Government	Land use planning	Preparation of long term land use plans with respect to industrial locations
3. Government	Urban development and industrial location	Proper location of hazardous industries. Controlling urban growth and squatter settlements
4. Firms selling technology from abroad	Selling technology	To ensure proper safety, and allow for extra safety considerations because of lower levels of skills of operators. Systems safety analysis should be carried out
5. Foreign collaborators	Regular inspection procedure on subsidiaries	Regular inspection of the safety procedures
B. FIRM LEVEL DECISONS		
6. Plant designers	Insisting on systems safety analysis	Design has to be re-examined to take into consideration safety and probable failures
7. Safety and occupational health	Industrial safety, protection of workers	Proper safety regulation and inspection. Tougher controls on hazardous and toxic material handling industries
8. Industrial Managers	Safety management	Regular inspection and rigid adherence to safety regulations. Proper maintenance schedules for critical components
9. Industrial Managers	Public relations	Give public awareness information on toxicity, hazards and precautions
10. Trade union leaders	Insist on safety standards	1. Create pressure for improving systems safety 2. Educate workers on occupational health and safety
C. REGULATORY AND CONTROL DECISIONS		
11. Department of Environment	Ranking hazardous and toxic substances	Assess and classify the toxicity of hazardous materials. Have proper regulations for controlling toxic materials
12. Environmental lists & Conservation lobby	Creation of public awareness	Environmentalists have to analyze the accident information and create public awareness
13. Toxicology researchers	Collect, compile and generate the necessary data	Create data banks on toxic materials, their effects as well as antidotes

IMPERATIVES FOR DECISION MAKERS

The 'Bhopal accident' (Rout, 1985) as it has been known, has immense applications. Some of the major imperatives for decision makers are listed in Table 5. One of the important issues is the lack of risk assessment procedures in developing countries (Bowonder, 1981, Bowonder, 1983). Industrial licenses are issued to industries based on their assessment of alternative technologies, and not based on all available technologies. There should be a multi-institutional agency for taking decisions on issues affecting hazardous or toxic materials. The major imperatives are the following:

- the proper location of hazardous or toxic industries including the re-examination of existing locations,
- firms selling technology from abroad should insist on the necessary safety precautions,
- government inspections should be made more stringent for toxic materials,
- trade unions, and other social groups, should take a deeper and more sustained interest in industrial safety and health,
- a general clause casting the responsibility for ensuring the safety, health and welfare of employees at work on the employer, should be incorporated in the statutes,
- legislation should make it necessary for the agencies responsible for accidents, to pay

compensation to the accident victims. Norms for compensation should be fixed to reduce the delay in getting assistance or aid. The Indian laws regarding compensation are very unscientific and *ad hoc* especially in relation to the responsibility of multinational corporations *vis-à-vis* their subsidiaries,

- parent organizations should make sure that their subsidiaries enforce all safety regulations,
- toxic materials should be classified and their use monitored. The storage of toxic materials needs to be strictly regulated and inspected.

CONCLUSIONS

It is easy in hindsight to analyze the Bhopal accident. In many instances the failure to adhere to the correct safety factors is nothing but negligence on the part of the plant managers. That MIC production started in 1979 at Bhopal, should have ensured the incorporation of the latest safety equipment and monitoring devices. If the subsidiary did not request the latest safety systems the parent company should have insisted on their installation. Further, allowing the manufacturing plant to be situated very close to a growing city, permitting the plant to expand its activities in 1977, allowing squatter settlements to develop close to the factory, and subsequently regularizing these illegal occupations, neglecting the safety aspects inspite of six known accidents since 1978, and permitting storage of large quantities of MIC, indicate that safety was given a low priority in government and industrial circles. The safety aspects should be rigorously inspected and reviewed in all major factories dealing with hazardous or toxic substances in India. Efforts should be made to classify hazardous and toxic substances and a safety review for highly hazardous and toxic substances should be made statutory. Industries dealing with hazardous materials should be sited away from human settlements and existing units, if necessary, should be re-located. There should be a long term industrial location plan, in the form of broad zones, across the country.

In chemical plants with complex interactions and tight coupling (Fig. 1) the strategies to reduce accidents have been identified (Perrow, 1984) as; i) centralization to cope with tight couplings; in the form of systems for immediate response, automatic sensors and detectors and unquestioned discipline, and ii) decentralization to cope with unplanned interactions of failures through careful and detailed search by those closest to the subsystems, through systematic operator training, regular and thorough inspection of critical safety components, and microprocessor based early warning and alert systems. Emergency drills should be carried out, and every organization and major city should have plans prepared for emergencies and major countries because of the soft nature of the administration and its poor discipline. Acceptable risk decisions reflect the nature of the society (Fischhoff, 1980), and in societies where the value attached to a life is very low, safety will be less well regarded and neglected. Safety systems can be changed only through public education and awareness. The Indian Factories Act should be made more stringent with respect to the reporting of accidents and suitable corrective actions subsequent to accidents. Regulations similar to the Occupational Safety and Health Act (OSHA) should be enacted to protect workers. In cases where hazard severity could be catastrophic, a system similar to that adopted by the US Nuclear Regulatory Commission could possibly be used to prevent oversights, errors and omissions (Gloss and Wardle, 1984). In large industrial plants, the whole interactive system must be analyzed for safety.

To conclude, the Bhopal incident makes it necessary for developing countries to re-examine their policies towards toxic substances. This should be undertaken in terms of, safety precautions, factory laws, compensation laws, reporting systems, crisis management facilities, the industrial location, design of systems, technology choice procedures, technology acquisition regulations, toxicology research, inspection and regulatory processes for risky systems, involvement of trade unions, and the government systems for risk regulation and control.

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APPENDIX — Chemistry of Methylisocyanate (MIC)

1. MIC reacts with water as

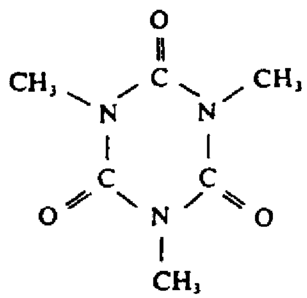
$$CH_3NCO + H_2O \rightarrow CO_2 + CH_3NH_2$$

Methylamine

2. The basic carbamylation reaction of MIC is

$$CH_3{-}N{=}C{=}O + ROH \rightarrow CH_3{-}N{-}C{-}O{-}R$$

3. In the presence of contaminants, MIC gets polymerized to cyanuric ester.



4. Phosgene removal mechanism

$$COCl_2 + H_2O \rightarrow CO_2 + 2HCl$$

results in the generation of hydrochloric acid, which catalyzes the polymerization.

5. MIC reacts with limited amounts of water giving the following products

$$2CH_3N{=}C{=}O + H_2O \rightarrow CH_3{-}NH{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}NH{-}CH_3 + CO_2$$

$$3CH_3N{=}C{=}O + H_2O \rightarrow CH_3{-}NH{-}\underset{\underset{\displaystyle O}{\|}}{C}{-}\underset{\underset{\displaystyle CH_3}{|}}{N}{-}\underset{\underset{\displaystyle O}{\|}}{C}{-}NH{-}CH_3 + CO_2$$

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