BHOPAL GAS TRAGEDY

DELHI SCIENCE FORUM REPORT

CONTENTS

Address for Correspondence
B-1, 2nd Floor,
J. Block, SAKET
NEW DELHI-110017
Phone : 66 50 36

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INTRODUCTION

THE disaster in Bhopal has been universally recognised as the worst ever industrial accident. Thousands of human beings, mostly poor, have lost their lives. Countless others continue to be seriously affected. Vast numbers have been permanently disabled. The long-term effects and possible genetic damage have yet to be estimated.

As members of the scientific community, the Delhi Science Forum is in deep anguish contemplating the implications of this immense tragedy. There is great danger that science and technology may come to be regarded as a source of death rathar than as a means of human advancement and the pursuit of happiness. It is, therefore, imperative that the public be taken into fullest confidence by the authorities. The official team of scientists and technologists entrusted with the task of inquiring into the tragedy, owes it to itself and to the entire scientific community in the country to lay bare all the relevant facts. It is in this spirit that the DSF is raising certain issues.

The tragedy has brought to the fore several issues : those on which immediate action is needed by the government to cope up with the situation created by the disaster in Bhopal and those aspects which are general in nature and would have to be addressed by revamping existing executive measures and legislation to prevent and manage the disasters like the one which occured in Bhopal. The tragedy also highlights the need for strengthening of institutions concerned with research, monitoring and control of delayed effects and second order impacts, monitoring and regulation of environmental pollution and occupational/ industrial health hazards. All these issues require concerted action.

An expert team is investigating the Bhopal tragedy. The DSF expects that this team, with the resources of national laboratories and other scientific and technical expertise available to it, will produce a report which would be informative, complete and detailed so that the data and conclusion could be cross checked independently by any other member of the scientific community and others. The DSF hopes that such a report would be forthcoming soon and would be freely available.

A DSF team visited Bhopal from 9th to 11th December, 1984. It met several disaster victims in the worst affected areas like Jaiprakash Nagar, Chhola and Kenchi Chhola. The team also met several operators and engineers of the Union Carbide India Limited (UCIL). Bhopal Plant and many local doctors and scientists all of whom provided much valuable information and insights. Other DSF members collected background material, held discussions with a variety of experts and helped in drafting and editing the report. The DSF is extremely grateful to all those who helped in the formulation and preparation of this document.

Criminal Negligence

Without prejudice to the on-going enquiry, the DSF has discovered sufficient evidence to show that there has been *gross negligence both on the part of the Union Carbide Corporation (UCC), and UCIL management*, in those critical areas which related to processing and handling of the hazardous MIC, phosgene and other toxic substances. Plant's maintenance was astonishingly deficient. Worse, many crucial safety functions were inoperative, some for "economy" reasons. Such "economy measures" were also responsible for a manning policy which depleted the plant's experienced and trained personel, overloaded plant staff and led to stationing of untrained personnel in critical areas of the plant.

The accident has also exposed the utter inadequacy of the safety equipment, even had they been in working order. The entire plant was utterly underdesigned with respect to standby systems, control and monitoring facilities, safety barriers, etc. Computerised monitoring and control systems had not been provided in the Bhopal plant, unlike in the U.S. parent plant. There is sufficient evidence to show that the entire technology package transferred to India in Bhopal is obsolescent.

Third world : Pollution havens ?

Our investigations have thus convincingly brought home once again, in extremely tragic form, the truth that multinational corporations operating in third world countries pay scant attention even to technological imperatives for ensuring human safety, in contrast to the measures they adopt under the vigilant eyes of the people of Europe and the U.S.A. The Bhopal accident starkly exemplifies the inherent tragedy of the logic of pursuing maximum profits at minimum costs, more so in third world countries whose populations are considered expendable by MNC's.

Nevertheless, India is obviously going to continue to import technology. It is thus essential to draw proper conclusions for our guidance in the future. It is clear that our government has not set up any mechanisms or means for a critical evaluation of technology. Such an evaluation is even more imperative in the area of industrial processes involving highly toxic and hazardous chemicals. In respect of the Union Carbide, for instance, questions immediately arise regarding the manufacture and storing of large quantities of MIC, safety equipment, and controls etc.

Dubious Research

Apart from the production plant, in the course of investigations made by the DSF team, certain intriguing aspects of the R&D setup of Union Carbide at Bhopal have come to light. This R&D effort relates to carbamate-based pesticides, a pilot plant and field trials in experimental farm plots. Recently, the UCIL's R&D representatives have entered into a collaboration agreement with the UCC(USA) to conduct experiments to synthesise new molecules, test them on tropical pests at Bhopal and supply the research data for an annual fee of US $ 300,000. The research is aimed at the development of pesticides suitable for tropical conditions and the facilities, reputed to be among the best in the world, include three green-houses and five insect-rearing laboratories. It must be noted that *this R&D covers the grey area between peaceful application and biological warfare.*

The ambitious expansion in R&D has been continuing at the cost of flouting even the minimum safety requirements. This naturally raises doubts about the real purpose of the R&D programmes. the DSF expects on-going enquiry to investigate this aspect also.

It needs to be noted that at present the information called for by government for the transfer of technology under foreign collaboration, in-house R&D recognition and re-newal, etc. do not focus on pertinent scientific and technical details or on in-depth assessment of these by S&T experts from national laboratories, defence organizations, engineering and design organizations and R&D units of public undertakings. Far greater nodalised emphasis is thus required in the decision-making, regulatory and follow-up mechanisms relating to foreign collaboration and in-house R&D recognition and renewal.

Broader issues

The Bhopal Tragedy, has also underlined the need for attention being paid to several broad issues. The scientific community must, in co-ordination with legal experts and informed public opinion, urgently focus on :

i) Factory laws

ii) Specific safety measures to be instituted under labour laws.

iii) Acts related to air and water pollution and their enlargement to cover wider environmental hazards.

iv) Laws related to production and use of pesticides, drugs, dyes, foodstuffs, etc.

v) Laws relating to compensations

vi) Laws relating to punitive action.

vii) Executive mechanism to implement and monitor the above.

In order that the above noted measures be effectively initiated and implemented, it is essential that pertinent informatin relating to these aspects be made freely available in published form for use by research organisations, S&T voluntary organisations, trade unions, consumer groups, professional associations, scientific societies and the general public. In many of these matters, there is at present *unwarranted confidentiality* usually justified on the basis of companies' interests. Open availability of such information would indeed assist the government in discharging its responsibility towards the people and in the specific instance of the Bhopal accident, such information, had it been freely made public, could have averted the terrible sufferings of this grim tragedy.

TOXICITY AND DELAYED EFFECTS

ALL the ingradients that go into the making of the carbamate pesticides at UCIL, Bhopal are highly toxic. At various stages of production the plant uses carbon monoxide, chlorine, phosgene, methylamine, chloroform, MIC, alpha-naphthol, carbon tetrachloride, etc.

With such an highly hazardous process being used at UCIL the details of which were not known and against a backdrop of numerous accidents in the factory from its inception, there was much confusion as to the nature of toxic substances released. Immediately after the accident, the UCIL instead of helping to clear the confusion added to it by giving contradictory statements. Confounding this confusion was the lack of knowledge of the toxic effects of the various chemicals used in the process. Many were inclined to believe that MIC is not very toxic and that such a large number of deaths could be caused only by phosgene.

Contary to the impression that MIC is "not so deadly", it is, in fact, an extremely lethal substance. In many ways MIC is more toxic than phosgene. The chemistry of MIC is very complex and relatively little is known of the toxicological effects of MIC. Its strong primary irritant effects on the respiratory tract, causing massive build up of fluids in the lungs consequent to large scale tissue damage probably accounted for the majority of deaths. In humans, exposure to mere 21 parts per million (ppm) causes suffocating effect and severe irritation of respiratory tract and eyes. According to literature available conversion to cyanide is not expecced to occur at significant rate in living organisms. The *post-mortem* studies have revealed the presence of cynanides, though the exact route for transformation is unknown.

The cause of death after acute exposure may be either bronchospasm or what amounts to drowning in released body fluids. Otherwise death could also result from the secondary effects of loss of blood oxygen and acidosis, or from congestive heart failure. Since the reaction products of MIC with various organic molecules in the living organism are also toxic, several complication involving liver and kidney would also result. Survivors of the exposure will be beset with numerous complications throughout their lives. According to Dr. Trent Lewis of the National Institute of Occupational Safety and Health (USA) survivors will probably suffer increased incidence of pulmonary fibrosis, emphysema and chronic bronchitis. The respiratory tract may become hyper reactive to a variety of irritants, and changes in lung tissues may increase susceptibility to infectious pneumonia. Those who are once exposed to MIC would develop acute allergic conditions as a result of sensitisation of the respiratory tract and a second exposure even if mild, could prove fatal. This could have happened in Bhopal, as the victims who received first aid, returned to an environment where MIC was still present, though in very low concentrations. Necrotic lesions of the cornea can lead to permanent blindness or impaired vision. Possibility of behaviorial and neurological disorders also exist because of the disturbance to the central nervous system.

Clinical Report

Victims began arriving in hospitals broadly with the following complaints. (Details based on the interviews we had with the medical aid teams working in different affected areas and hospitals) :

Severe chest congestion
Foreign body sensation in the eyes
Diminished and blurred vision
Whiteness in the eye
Frothing at the mouth
Headache and giddiness
Sore throat
Pain and burning sensation in the chest
Coughing and breathlessness
Vomitting
Abdominal cramps
Diarrhoea
Swelling of legs
Palpitation
Vomitting of blood
Weakness of tongue and limbs
Paralysis
Stupor

Chills
Cold/clammy skin
Coma
Fever

Severe chest congestion was present in almost 100 percent cases and eye problem in 90% cases.

Nearly all had complaints related to chest (pain, cough and breathlessness)

Headache, giddiness, vomitting were also very common complaints.

Symptoms related to abdominal pain were less common. Diarrhoea was being experienced in about 10 percent of the cases.

Clinical picture of the victims who presented themselves after some delay does not differ much except in the following ways :

(a) Eye problems were somewhat less

(b) Fever, chills and chest complaints were common suggesting development of secondary infections.

(c) Many patients had earlier experienced a little discomfort and some of these had to be hospitalised.

(d) Many had been discharged earlier without proper treatment.

Line of Treatment

No official line of treatment was available till the team left Bhopal (11th December). No specific antidotes for the MIC poisoning were available to the doctors. Sodium thiosulphate was used in certain cases suspecting cyanide poisoning, on the 10th and 11th December but given up later as not found effective. General lines of treatment were as follows :

(i) To reduce inflammatory conditions, intramusular decadron i.e. steriods, was administered.

(ii) Aminophyllin intravenous injections were given as broncho dilators ; and

Antacids were administered to reduce stomah irritations.

Apart from these some intramuscular and intravenous preparations of atropine sulphate, adrenaline, lasix, nekethenamide were also administered. To start with, treatment followed from the belief that the patients had suffered from some kind of organo phosphorous poisoning. The injections were being given on the indications not specified. In the initial period atropine sulphate was injudiciously and widely administered and only later, after 5 days, was it stopped, on the ground that it is making secretions viscid, causing tachcardia and producing myscardialanoxamia (i.e. oxygen requirements of heart increases due to this treatment).

In the same fashion, lasix was also later stopped since it was causing dehydration. Adrenaline and nekethenamide were used less frequently. Injections of sequil were used against vomitting. Widely administered tablets were aminophyllin, antacids and avil. Antibiotics and corticosteroids which were essential were not available in sufficient quantities.

Sulpha or antibiotic drops were used for eye problems. The use of other drugs like atropine and corticosteroids for eye complaints became controversial and there was total confusion regarding the use of these drugs. Finally, their use was declared to be non-essential in all cases by experts who arrived from Delhi. While patients slowly recovered from complaints of blurred and diminished vision, nothing can be said definitively about cases where eyes were severely affected.

Results from Postmortem Studies

Autopsy findings have revealed cerebal oedema apart from massive pulmonary oedema; massive destruction of lung tissues; demaged lever and kindneys; and ananolous coagulation of blood, i.e. large amounts of blood coagulated, leaving parts of the circulatory system completely drained of blood. There were cases of hearts full of coagulated blood as well as cases of hearts drained of all blood. As mentioned elsewhere in this report, cyanide was also found in the blood.

Pathology reports show leucocytosis (increased levels of polymorphs) and increased blood urea which in certain cases had gone up to 80 to 90 percent as compared to normal levels of 20 to 40 percent.

Studies of water bodies in the severely affected areas show high fish mortality rates.

Casualties

The tragedy at Bhopal has parallel only in the use of poisonous gases in chemical warfare. Phosgene, small amounts of which were present in the nearly 45 tons of MIC which got released into the atmosphere of Bhopal and neighbouring areas, was in fact used in World War I and II and the Iran-Iraq war. Given the nature of these gases and due to the fact that a substantial section of the population was also exposed to them in non-lethal doses, the effects of which could manifest over long periods of time, makes it difficult to arrive at definite estimates of the casualties.

The DSF team would at this stage make a conservative estimate of nearly 5,000 deaths, although estimates quoted in Bhopal vary from 2,000 (quasi-official estimate) to 10,000. Many of the medical teams engaged in relief operations (for instance from Gandhi Medical College, Bhopal) tend to agree with our estimate.

Accompanying map depicts the spread of toxic gases over the Bhopal city. The areas of residential density per hectare indicated in the map refer chiefly to the gas affected areas. It can be seen that areas where gas concentration was the highest after the accident also coincides with the most densely populated areas. It is clear that irrespective of whether slums had come up near the factory area or not, the demographic distribution of the city, clearly shows that even without the presence of slums, the industrial area where UCIL plant is located is close to the region of highest residential density, the Old Bhopal.

Table 1 prepared after consultations with the medical aid teams shows the percentage of fatalities in some of the localities.

The total number of people severely affected could be put at around 20,000 (excluding delayed effects cases). Considering the immediate impact zone of the accident, the total number of people requiring serious medical attention and follow up can undoubtedly be placed at around 50,000. The total population of the area immediately affected by the gas spread is about 2.5 lakhs of which nearly 1.5 lakh live in areas over which the gas settled in high concentration. The vast majority of the population in the most affected areas live at or below subsistence levels.

TABLE : 1

Estimated Percentage of fatalities in certain affected localities till 11th December 1984.

J.P. Nagar Chola Chola Kenchi	20–25
Railway Station Railway Colony & nearby area Dwaraka Nagar Berasia Road Kazi Camp	10–15
Khajanchi Bagh Chandbad Sindhi Colony Bhogdepur	5–7
Bus Stand Islampura Bhopal Talkies area Tilla Jamalpura Shahajahanabad Berkheri Ibrahim Ganj	1–2
Mangalwara Ashoka Gardan Chawari Professors Colony North T.T. Nagar Nav Bahar Colony Garam Gaddha Area Near Railway Bridge	Less than 1

Medium and Long-term Effects

As mentioned earlier. cyanides were found in the blood and viscera of those who fell victim to the gas. Reasons for the formation of cyanide in the blood stream are yet unknown although it is speculated that some of the reactions of MIC with blood haemoglobins would have led to this. Due to the guidelines issued to investigating scientists emphasising tests for MIC-related compounds. very little is known of the effects due to phosgene poisoning. The team is of the opinion. that both MIC and phosgene were present in the gas clouds that had spread over a large. densely populated area : traces of phosgene are always present in the MIC tank since it is used as inhibitor.

The team. after consultations with various scientists and medical experts. is convinced of the need to look for the effects that a mixture of large amounts of MIC and very small amounts of phosgene could have. as most certainly is the case in the Bhopal tragedy. The team shares the apprehensions of a number of medical workers who fear large-scale outbreak of delayed effects and secondary infections as well as relapses.

As pointed out earlier. the vast majority of the most severely affected people are those living in near starvation conditions. Many of them already suffer from various types of diseases especially those related to the chest and weakness of body due to overwork and under-nutrition. Already victims of over-exertion and occupational hazards. the colonies they live in now resound with the sound of coughing and gasphing. Very soon they will have to either return to work or starve.

Secondary effects

All this would imply a delayed outbreak of bronchial diseases. infections pneumonia. T.B. and various forms of allergic conditions. The health of pregnant women and infants is still an open question as are possible genetic effects. The very fact that MIC would give an endless variety of products on reaction with other organic molecules under various conditions that obtain in the living organism would tend to confirm these fears. Almost every type of catalysts (see table of catalysts promoting various isocynate reactions. Appendix 3) which helps MIC give different kinds of reaction-products with other organic molecules is clearly present in the living organism.

The toxic gases, on reaction with water and various organic materials (plant and animal tissues specially in living condition), give rise to a large number of complex products many of which are highly toxic. The possibility thus exists of cattle feeding on affected plants, and contaminated animal and plant products being consumed later on by human population. The biological magnification of the concentration levels in this manner is well-known as in the case of mercury poisoning through consumption of fish which is well known to the scientific community. Also well known is the presence of DDT in mothers' milk, resulting from slow accumulation of DDT by consumption of food grain having traces of such chemicals.

Need for rigorous investigations

As regards water, the DSF team is doubtful if detailed sampling has been done. A large number of samples have certainly been collected. However, they are mainly from the two big lakes (Upper and Lower Lakes of Bhopal). The small ponds and other such sources of water which are often the main sources for the poor in many parts of the affected areas have hardly been subjected to intensive sampling and tests.

The DSF team is of the opinion that on the basis of available meteorological and topographical data of Bhopal detailed gas diffusion modelling and simulation studies of the dispersion pattern of the gas discharge into the atmosphere need to be undertaken. The team found it impossible to get any data on the existing concentration levels of MIC, phosgene, carbon monoxide and other compounds which are bound to be present in varying degrees of concentration at various distances from the UCIL plant and at different heights. It is fairly certain that no such studies or air samples have been undertaken by the expert team entrusted with this job. If such studies have not yet been carried out, the public needs to be told of the exact nature of th studies undertaken so far. Given the fact that the highly sophisticated equipment required to carry out such detailed studies is not available at Bhopal, it is necessary to collect samples and despatch them to places where such equipment is available. It has also come to the notice of the team that fish, plant and animal tissue samples are still only in the process of being sent to the ITRC for detailed tests. (i.e. on 11th December, 1984).

The short and long term effects of the massive MIC pollution on crops and vegetation deserves to be intensively studied for the contamination of vegetables as well as the effect of the toxic gases on plant growth, and heredity of standing crops and vegetable in the area within the gas spread. Dr. R.H. Riccharia, at one time director of the Central Rice Research Institute has pointed out that nuclear abnormality was bound to occur in plants exposed to MIC and has suggested the need to indentify cultivated fields with standing crops, in the area within a distance of 50 Km. from the site of UCIL. According to Dr. Riccharia samples of the harvests in February-March next of all the standing crops falling within these areas must be taken up for analysis.

Poor equipment, restricted information

Lack of sophisticated equipment and instrumentation severely impedes the investigation. Another major handicap for the scientist members of the team constituted by Government as well as those working independently on their own—is the lack of up-to-date scientific literature on various aspects. In the face of such difficulties scientists have found it nearly impossible to evolve methods, for instance, on non-destructive testing of phosgene. Much of the results of the findings in these areas are also quite likely to have never been published given the enormous significance such data has for chemical warfare. Such information is of immediate importance in dealing with the fall out of the present tragedy. The world at large must know all aspects of poisoning due to such toxic gases.

In sharp contrast to the total clamp down on information and discouragement to Indian scientists willing to undertake independent studies, is the complete freedom with which such foreign "experts" who are known to be associated with the foreign defence research laboratories, are collecting detailed information, in Bhopal. They are also conducting detailed studies on their own. Concern has quite rightly been voiced, at least, in some sections of the press of their implication, in Bhopal. Such studies, meant for chemical warfare data-gathering, must be immediately stopped.

Health Care and Monitoring of the Affected Population and Areas.

A machinery must be set up for health care and monitoring of the affected population in the area. This should involve the entire people of the area and non-governmental organisations. The following aspects need to be covered in this scheme :

(1) Immediate setting up of health care machinery specifically for these areas with close links to the community.

(2) Preparation of detailed medical histories of all families in the affected area, without delay, so that the later evolution of their medical histories could be kept track of.

(3) Periodical medical examination of the families and updating of their medical histories.

(4) Ensuring that all deaths and births are recorded in the area with medical reports on the causes in case of death and health conditions of infants and mothers in case of births.

(5) Recording of incidence of respiratory and lung diseases including T.B., pleurisy, infectious pneumonia., allergic conditions, asthma, cancer, etc.

(6) Recording of the incidence of outbreak of infections and the level of immunity of the people in these areas to the diseases.

(7) Recording of the incidence of liver and kidney related disorders including outbreak of jaundice.

(8) Survey for the incidence of neurological and mental disorders.

(9) Survey for the effects on livestock and vegetation.

(10) Detailed monitoring of plant, animal and aquatic life for genetic defects and other long-term effects.

(11) Standing crops in the area of gas spread be subject to detailed investigations by agricultural experts.

With respect to the above it should be noted that this was the first major accident involving release of MIC as a gas. All previous accidents relating to MIC have been the leaks of MIC as liquid in small quantities. There is no detailed information available regarding the effects of MIC and possible line of treatment to be followed to control the delayed effects. There is hardly any authoritative scientific work available on the consequences of exposure to MIC. Despite widespread use of methylisocynate, the world scientific community has done little work on the consequences of exposure to MIC. Inferences about long-term consequences of Bhopal tragedy are based mainly on available knowledge of the related substances like toluene disocynate widely used in the manufacture of various polymers.

In the monitoring and relief operations, the machinery should involve the widest cross section of the scientific community including voluntary organisations. Involvement of the voluntary non-governmental scientific and technical organisations is a must for the government if it has to restore the faith of people and succeed in reaching all the victims of the gas tragedy for medical relief. Apart from involvement of the voluntary scientific effort in restoring the faith of people, educations of the public has emerged to be a priority task which should be tackled on an urgent basis.

THE DISASTER : MODE AND BACKGROUND

THE crucial question of how a calamity of such gruesome enormity occured cannot be seen in isolation from the complete subordination of safety codes, preventive maintenance and manpower policies to the singular task of increasing returns. This would become clear when a variety of information on the operation of the plant and the sequence of events at UCIL on the 2/3 december, 1984 are pieced together to give a self-consistent explanation.

Nature of the gas

Confusion surrounding the nature of the gas-whether it was MIC, Phosgene or a mixture of the two or something else—can be removed only when complete process details of the UCIL plant, a closely guarded secret of UCC (USA), are unravelled. However, contrary to the claims of UCIL, Bhopal on the sequence of operations and the factory lay out, unambigously shows that a very small amount of phosgene *is* allowed to be present in the MIC as an inhibitor that prevents the onset of self-addition reactions like dimer and trimer formation in the stored MIC. Various other compounds are included to prevent runaway reactions. All these substances are carefully monitored : excess amounts of these traces must be controlled since they may also act as catalysts for several uncontrolled reactions. It is not known whether these control standards were maintained and how many of them had been sacrificed for economy reasons.

State of safety systems

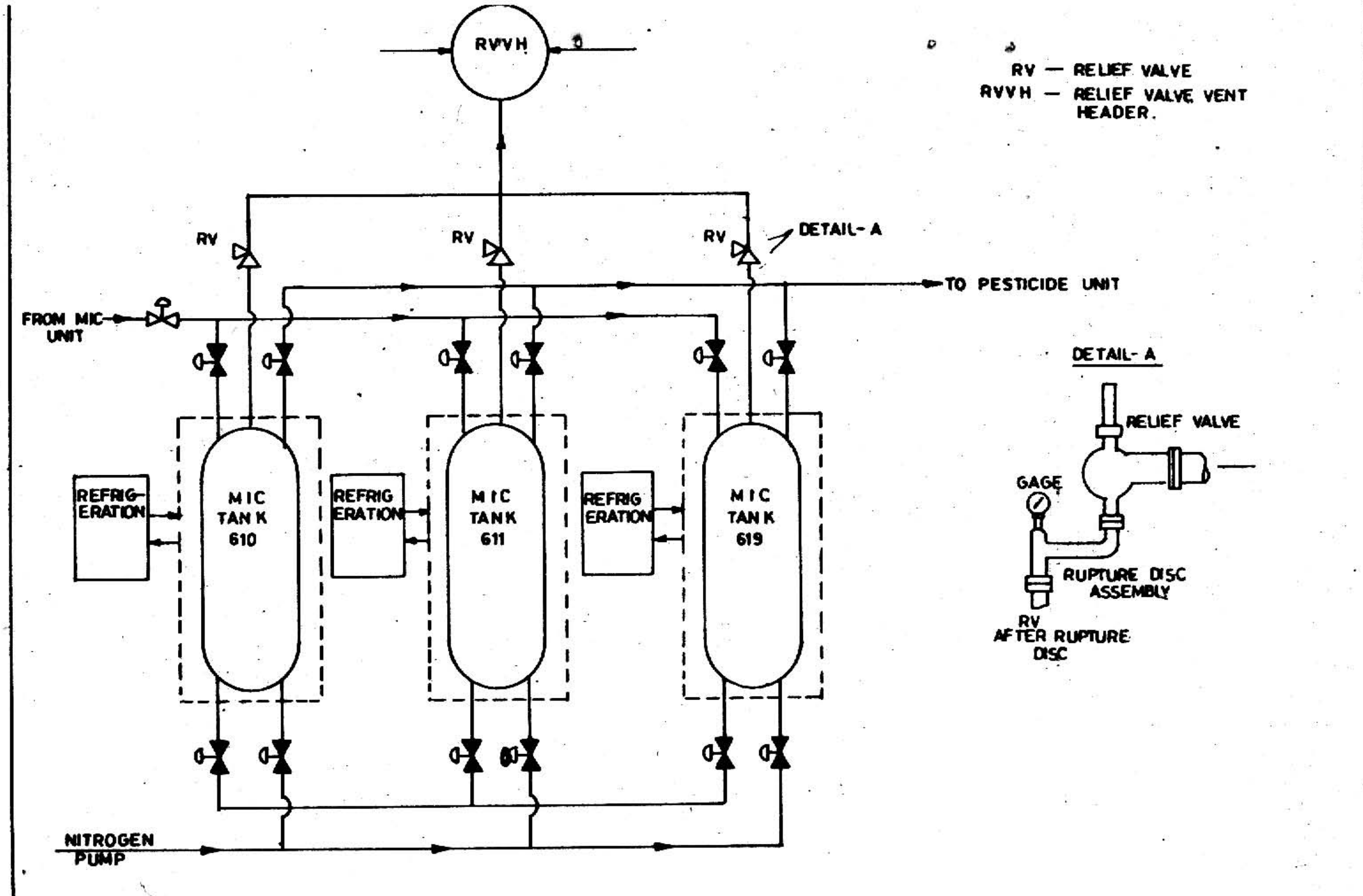
Several parts of the safety system comprising the Relief Valve Vent Header (RVVH), the Vent Gas Scrubber (VGS), and the Flare Tower were hardly in satisfactory condition. At the time of accident a vent line leading into the RVVH was being washed, the line connecting the VGS to the flare tower was master carded for repairs, the motors meant for pumping caustic solution into the VGS were down and certain meters in the control panel monitoring the MIC tanks were malfunctioning.

The chilling unit has been switched off as an economy measure. Many valves, vent lines, feed lines, etc. are in poor condition; items which should have been replaced every six months have been over used for two years. Poorly maintained valves, feed lines, and equipment could lead to conditions where certain chemicals could gain entry into parts of the plant where their presence, even in minute quantities, can start off run away reactions. (See diagrams for layout of safety systems and MIC tank design)

Runaway reactions spell disaster

Many features of the accident point to the possibility of the onset of uncontrolled reactions in the MIC tank (tank No. E 610) through mixing of water or caustic. Water was discovered by the workers after the accident when they drained the vent lines connecting the tank E-610 and RVVH. Similarly, caustic was found in the RVVH when the workers in emergency shift opened it on December, 10. If this indeed was the case many questions come to the fore. If samples of stored MIC from each of the storage tanks are tested every day for control standards and found to be contamination free in the quality tests in the analysis laboratory of UCIL, how did uncontrolled reactions set in? Could large amounts of water enter the tank as many think, passing through the valves that isolated the tank/RVVH from the vent line that was being washed, the one way relief valve (RV) and the rupture disc (RD) of the MIC tank? Could such flow backs into the tanks go unnoticed or were the monitoring facilities in the control room woefully inadequate to monitor such hazardous developments? What were the facilities, or did any facilities exist at all, at the UCIL to cope with the possibilities of rapid build-up of oxothermic reactions due to contamination of MIC in the storage tank? Can the rate of outflow (nearly one ton per minute), the rate temperature and pressure build up etc. be sufficiently accounted for by the reactions that could have triggered off these developments? All these questions and many more would have to be answered in a consistent manner.

The exact process used and much of the information on the hundreds of reactions of MIC with other inorganic and organic


RVVH
RV — RELIEF VALVE
RVVH — RELIEF VALVE VENT HEADER.
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DETAIL- A
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RELIEF VALVE
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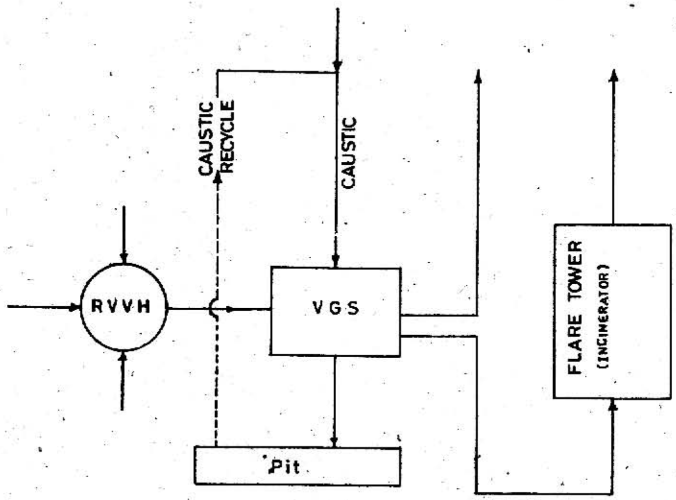
MIC TANK 619
NITROGEN PUMP



V.G.S. :- VENT GAS SCRUBBER.
R.V.V.H.:- RELIEF VALVE VENT HEADER.

SCHEME OF VENT GAS SCRUBBER & FLARE TOWER.

compounds are all well guarded secrets of the UCC(USA). However, even, without detailed knowledge of the process used, the known reactions of MIC should give us clues as to the various possibilities such as self addition reactions (dimer and trimer formation), polymerisation etc., in the presence of certain chemicals or water which could have some how found their way into the MIC tank. Many of the impurities that could have gained entry into the MIC tank and their reaction products with MIC would also act as catalysts triggering off uncontrolable run-away reactions causing temperature and pressure build up (See appendix 3 for summary list of such catalysts). However, in order to gain entry to the MIC tank these chemicals or water would have to get through the relief valve (RV) which is meant to open only when pressure exceeds the permitted limit inside the MIC tank. Even if the RV was faulty or passing while in the normally closed condition, chemicals or water did pass through in whatever small quantities through the RV. Still in order to come into contact with the MIC, it has to penetrate through the rupture disc (RD) as well. The RD, which is gas-tight seal, is designed to rupture only when the pressure builds up inside the tank beyond a certain threshold value set at a value lower than the set value of the RV. Since RD acts as a gas-tight seal till it is ruptured by the excessive pressure build up, chemicals could have reached MIC only if this seal was also faulty. (See diagram of RV-RD assembly).

Faulty storage system

There were several indications that all was not well with the MIC tank E-610 and its valves. Many pieces of the puzzle would seem to fit together when the information gathered from workers manning different parts of the plant or engaged in repair work are sorted out.

The fact that many things were wrong with tank E-610 is curiously enough the easiest to confirm. At least from the 30th November, 1984 if not before, the meters monitoring the tank were giving abnormally low pressure (whereas a pressure of 20 PSI gauge is normal, E-610 meter was showing only 2 PSI gauge). It is not known whether this was in fact due to faulty meter or due to the inability of the tank to maintain pressure. If the latter was indeed the case, the meter would have indicated low pressure irrespective of whether it was faulty or not. In the case of former eventuality, pressure build up would not be noticed at all.

It is not known what corrective measures were taken or whether any effort was made to ascertain the condition of the rupture disc (RD) and the overall condition of tank No. E-610. If the RD had ruptured, the pressure gauge connected between RD and RV should indicate build up of pressure (it would otherwise read zero). (It needs to be noted that this crucial pressure gauge has to be manually monitored and is neither linked to the control room nor to an automatic warning alarm. In the West Virgina Plant of UCC it is linked both to an automatic warning system as well as the control room). It is not known whether these aspects were checked up eversince the abnormal readings were observed in the control room. However, it is known that efforts were made on 2nd December to pressurise E-610 by pumping in nitrogen. Nevertheless, the control panel reading did not show any change. It seems as if the meters were stuck or inoperative. Subsequently, an attempt was made to feed the SEVIN plant with MIC from Tank E-610. The attempt, however, failed and SEVIN plant was instead fed from MIC tank E-611.

It is possible that the attempt to pressurise tank E-610 further damaged things and may have caused RD to rupture. If the RV also was passing, nitrogen could have escaped into the RVVH in which case the pressure guage would not have registered.

The faulty safety valves and the rupture disc could have thus facilitated the entry of small amounts of water, caustic solution or vapours into the storage tanks. It is evident from literature on chemical technology that even small quantities of these substances are sufficient to the start off various types of highly exothermic (generating heat) reactions. These substances could thus provide the necessary heat and act as catalysts for several reactions like dimer, trimer or even polymer formation. The rapid heating of MIC would lead to fast gasification. MIC being highly volatile with BP of only 39.1°C. The consequent pressure build up inside the tank would release the gas into the RVVH. These reactions are totally uncontrolable. Build up of pressure and temperature can then cease only when the tank gets emptied.

Self addition reactions like trimerisation and polymerisation are likely to set in when isocynates are stored for long periods. (See appendix—1). It is, therefore, necessary that the stored MIC be regularly monitored for such developements which could become uncontrolable. At UCIL, however, though MIC was filled in the tanks nearly three months back, regular monitoring was not being carried out on the MIC stored in tank E-610, ever since it was filled, to ascertain the onset of such reactions.

Pressure builds up

The various facts relating to the accident seem to fit these possibilities. When the control room noticed that the meter readings relating to tank E-610 were indicative of malfunction, the instrumentation centre of UCIL was promptly informed. The decision to feed MIC into SEVIN plant from E-611 following the failure to feed it from E-610 was taken in consultations with the plant authorities. At around 11.00 PM on 2nd December, the second shift workers had noticed temperature rising in tank E-610. Since this signalled a significant development, senior plant officials were informed and a mention of suspected MIC leakage entered into the log book. Senior officials of the UCIL including the Manager were on the spot to monitor the developments and issue necessary guidelines. At around 11.30 PM even though the developments were getting out of control, no effort was made to initiate steps for alerting the people in the neighbouring areas. It must have been clear to the top officials of the UCIL that the way things were going, even the possibility of an explosion of the MIC storage tank was on the cards.

The build-up of reactions were aided by the lack of chilling of the tank. It has already been mentioned that the chilling unit had been switched off as an economy measure.

Safety systems fail

Once toxic gases got released uncontrollably, even the rather heavily underdesigned safety system, which could have at best neutralised a small part of the 40 tonnes of MIC, was also not in a satisfactory condition. The caustic pump was down rendering it impossible to charge the vent gas scrubber (VGS) once the meagre amount of caustic charge in it was exhausted. The absence of a standby system, using passive flow from overhead tanks could, perhaps, have saved the situation to some extent. However, even if the VGS system had worked at its best, it was inherently incapable of dealing with this quantity and rate of gas escape.

The line connecting VGS and the flare tower meant for burning off the unneutralised toxic gas was also mastercarded (blanked-off) for repairs : this line has suffered extensive corrosion due to neglect. This system was also not backed up by a parallel line the installation of which does not require major works. It must be noted that the flare tower too was inadequate to burn off such large scale escape of gases.

In its very design, therefore, the entire safety system was not equipped to tackle such a major mishap.

Design Considerations of the Safety Systems

Though a detailed analysis of the design problems in the UCIL plant will need more data, certain preliminary problems have been already identified. It has been noted that initial protective measures were to be initiated manually and were not automatic as it should be for such vital functions. For instance, the vent scrubber was to be activated automatically. There were three MIC tanks in which one tank was always empty. In case of a pressure build up in one of the tanks, a portion of the gas could be bypassed into the empty tank. However, here also, the entire set of operations were manual and not automatic. In the panic of an accident, it is always possible that such measures are not taken manually, as it happened in Bhopal also. Further, an overhead tank of caustic soda would have ensured scrubbing of the vapour even in the event of failure of the pump.

The scrubber was underdesigned with respect to the gas stored. The rate of neutralisation was designed to be 5 tonnes in the first half hour with an additional ton every succeeding half hour. With this rate of neutralisation, at most 12 tons would have been neutralised against 40 tonnes stored in the tank. It may be noted that in Europe, safety systems have to be mandatorily designed on a worst case scenario. Vital instruments were also not connected to the control room as already noted earlier. Adequate redundancies regarding vital equipment like pump/motor, pressure gauges had also not been provided for. A thorough examination of the safety systems as designed by UCIL and their US principals need to be undertaken to identify their culpability and eliciting certain basic principles with regard to such systems.

Wrong manning policies

Apart from the poor preventive maintenance, the under-designing of the safety features, dependence on manual operations, the manning policy of the management compounded the already serious problem. The secretiveness of the the UCC and the UCIL in respect of various chemical processes involved, meant that the plant operators were not fully aware of the implications of the various operations they were called upon to perform. Rigorous training and education of the workers had suffered due to the economy drive of the management. The poor safety discipline also resulted from the placement of inadequately-trained workers in the gaps left by large scale removal of the trained staff.

In the company's economy drive, measures of retrenchment, incentives for voluntary retirement and policy on workload manning and training have been prominent during the last two years. A large number of skilled and well trained personnel have left the firm. The company has been giving incentives for voluntary retirement, offering additional benefits ranging from Rs. 12000 to 25000 for different level of middle level technical manpower. The company also has been taking economy measures in respect of manning of the plant. For the MIC plant where there used to be earlier 8-9 operators, the company has reduced the strength to five with one extra in emergency. This resulted not only in increased workload for the remaining personnel but also stationing of untrained personnel in various crucial sections of the plant.

The MIC and CO plants, separated by more than 100 feet, used to be supervised by two different production supervisors each specifically trained for their tasks. Now there is no separate production supervisor for the MIC plant. Instead, the CO plant supervisor is incharge of both the plants. This would have been unthinkable in the early phase of UCIL. The intensive training and evalution programmes that were in vogue at the early phase have now been completely discarded. Also the fail-safe principle of having one additional person besides the minimum necessary at each station (e.g. staff of two at the 15 feet wide control panel had been reduced to one)—which had been dramatically emphasised while the plant was being set up had been abandoned.

It is clear that the company's drive for making profits and effecting economies has been at the expense of safety and well being of its workers and that of the city's population. The scope of enquiry must be widened to include investigations into all the economy measures implemented by the management in the last few years. Full implication of the incident and the lessons that need to be drawn would become clearer only when all the issues raised are seen in their interconnections and full scope and brought into the ambit of the enquiry underway.

TECHNOLOGY TRANSFER :
Lessons for the future

WHAT are the lessons to be drawn to ensure that such a disastrous tragedy does not repeat ? The first step is to fully understand the Bhopal accident in all its dimensions. Such an inquiry must cover not only the sequence of events on the fateful day, the pattern of failures in the plant, but also the very policies and agreements which form the all-important backdrop to the disaster. In the long term, it is the general question of technology transfer, its evaluation and monitoring, which must be addressed in order to strengthen Indian S&T expertise and its abilities to prevent and tackle such industrial accidents.

This section, therefore, looks at the UCIL Bhopal plant itself. What is the technology involved ? What safety equipment was made available ? In sum, what were the modalities of the technology transfer from UCC, USA ?

The UCIL uses two lethal compounds—Methyl isocyanate (MIC) and phosgene for the production of the pesticide carbaryl (Sevin) at its Bhopal plant. Production of carbaryl using imported MIC was started in 1969. In 1977, the company entered into an agreement with UCC (USA) obtaining the technology for production of MIC which commenced in 1980.

Obsolete technology

Right from the beginning, the plant was beset with accidents. Contrary to the impression sought to be created by UCC, USA, that their hands are clean, it has become clear that the basis for the present tragedy had actually been laid in the very technology that was transferred to India for the Bhopal plant. Some reports have even suggested that the MIC plant at Bhopal was transferred second-hand from the MIC plant at Danbury, USA, while others claim that Canda had earlier refused permission to site this plant which was then shipped off to Bhopal. In any case, the MIC plant transferred by the UCC, USA to the UCIL was apparently ousolete and unsafe.

The imported plant had a production capacity far greater than the production planned for the Bhopal factory. Demand for MIC-based pesticides in India has been far below the output possible from the Bhopal plant. The Bhopal plant had thus been running steadily under-capacity. The problem of high cost of maintenance was, therefore, already partly built-in.

Safety and control systems : West Virginia *vs* Bhopal

As already noted, the Bhopal and American plants, although identical in production systems, differ significantly in respect of instrumentation and controls employed. The American plant in West Virginia employed computerized safety system (introduced in the early '70s itself) which is absent in Bhopal plant. Most of the controls in the Bhopal plant have to be mutually monitored and operated. The Bhopal plant is furnished with only one manual back-up alarm system instead of the four-stage alarm system required in the USA.

Designing safety into the systems to take care of the worst possible scenarios means building extensive redundancy. For example, the scrubbers and the flare tower were not designed to deal with the kind of event that Bhopal unit was faced with on 3rd December. That the Bhopal unit employs obsolete and relatively unsafe technology can also be seen from the fact that the plants abroad including the parent plant of UCC at West Virginia in USA, do not use systems which require storage of MIC in large quantities. MIC produced in these plants is instantly converted into the end products which are safe to store. The storage of MIC in large quantities is considered undesirable from the safety point of view.

Regulating storage of MIC in developing countries

Information available from the developed world suggests that, in several European countries, by law the firms processing MIC have been prohibited to store it in large quantities. They permit MIC to be stored only in liquid form in small quantities, in small containers and even then also for short periods of time. France does not even permit the manufacture of MIC on its territory. In Britain, a division of Ciba-Geigy Chemicals Ltd., is the only company permitted to deal with the MIC Located two miles from Grimsby, a town of 92,000, the firm imports and stores the chemical in 45-gallon stainless-steel drums. No more than 60 tonnes of the chemical is kept in stock at one time. MIC is stored in France and West Germany under elaborate control systems, inspection procedures and safety measures. The safety measures are designed to take care of the worst possible scenarios. In France, La Littorale, SA, a Union Carbide affliate is the biggest stockpiler of MIC. It imports the chemical from the U.S. in highly protected drums carrying 213 kg., each of which must be handled separately and which cannot be stacked together. The drums are stored in separate sheds equipped with water sprinklers which are automatically activated by gas detectors that set off an alarm in case the concentration reaches a certain low-level-measured in one hundredth or one fiftieth of one part per million.

Alternative technologies for Carbonate pesticides

There is another fact which needs to be investigated. There is a process patented by UCC, USA, which employs a two-step process : first, reaction of sodium-l-napthoxide with phosgene and second, the intermediate product is reacted with methylamine to give l-napthyl-n-methyl-cabamate avoiding altogether the problem of production and storage of toxic MIC. Although this two-step process too uses phosgene in the manufacture, but since phosgene is not stored in large quantities and is produced in a continuous process, the technology should pose less dangers. The question arises as to why this process has not been commercialised uptil now.

Safety systems technology : broken promises

In 1983, when the know-how agreement for MIC production technology between UCIL and UCC was renewed, the management specifically promised the Indian Government that it would ensure transfer of know-how for all the safety measures including the equipment required to tackle emergencies like sudden release of gases and fire accidents. The promise was made earlier in September, 1982 also when UCIL had sought the letters of intent for the manufacture of 200 tonnes of methabenzthiazuron and 50 tonnes of propofur per annum. Why were these promises not fulfilled ?

Partial transfer of know-how increases hazard

It appears that the parent firm has never considered it important and desireable to part fully with the know-how package to India. The technology for the production of MIC is governed by the rather heavily restrictive American Export Regulations. This technology is placed in the Munitions list under the International Traffic in Arms Regulation (ITAR) Act and administered by the Department of Commerce and Department of State in consultation with the Department of Defence. India is a "Category V" country under the US Export Regulations requiring case-by-case analysis. Whereas an exception was made during 1978-79 in terms of the regulations to export this technology in India, other technologies, which had dual-use implications such as spare parts for the nuclear power programme, components of launch vehicles and computers were not allowed or the applications left pending. It appears that the permission for export of this technology was granted partly because it did not involve transfer of the latest technology but only an obsolete one.

Secrecy harms safety

Even for this obsolet technology, secrecy of the highest order is expected to be maintained by employees of UCIL. So absolutely rigid is the Union Carbide's monopoly and control over information on the process that its employees, at the time of appointment, are bound by a secrecy agreement, proscribing them from divulging any technical information to outsiders. Employees are never permitted, not even during training, to take the company's specialised literature and safety manuals outside its premises. Notes can be taken down only with the sanction of the Manager. The manuals themselves are kept in the safe custody of the Manager. All these restrictions stipulated by the UCIL board, where UCC (USA) is well represented, are responsible to quite a large extent for the paucity of information on MIC and the production process.

Need for assessment of technology and safety

The deaths in Bhopal are a sad commentary on the absence of technology assessment and implementation of safe-guards in the decision making processes with respect to foreign collaborations approval and recognition of in-house R&D. In order that these deaths may not have been in vain, the governmental authorities owe it to the people to monitor, regulate and control the foreign collaborations, especially in the areas involving any hazards whatsoever. It needs to be noted that at present the information called for approvals of foreign collaborations and in-house R&D recognition and renewal does not focus on pertinent scientific and technological details and their in-depth assessment by the S&T experts from the national laboratories, engineering and design organisations and in-house R&D of the public sector undertakings. Far greater nodalized focus is required in the decision making and regulatory and follow-up measures related to

— foreign collaboration approvals, and

— in-house R&D recognition and renewal.

RESEARCH AND DEVELOPMENT IN BHOPAL

IN THE course of investigations made by DSF. we also came across an intriguing aspect of an UCIL R&D set up in which the company has continued to expand investment despite the losses in the plant and when the management had been taking measures like neglecting of preventive maintenance. effecting retrenchment. giving incentives for voluntary retirement and imposing a new manning policy. So much was the rationalisation in the investment in plant that the economy measures began telling on the safety and maintenance and repairs.

Increasing investment in R&D

The increase in investment in R&D at the Bhopal unit has included recruitment of additional highly trained manpower and setting up of the new pilot plants and the facilities like IR Spectrophotometers. NMR Spectrometer. L.P.L.C. (2 Nos.). etc. During the last three years. the company has recruited 8 Ph.Ds.. 13 M.Scs. 6 Graduates and 3 undergraduates in the R&D laboratories attached to the Bhopal plant.

The R&D unit in Bhopal was set up in 1976 with an initial investment of Rs. 2 crores which has been increasing. The company's R&D expenditure for the period 1978-84 towards capital and recurring costs is given below in the table :

Rs. '000

	Past 3 years (actuals) 1978-1980	Current 1981 (budgeted)	Next three years (estimated) 1982	1983	1984
A. Capital	3864	750	1000	1000	1000
B. Recurring	9746	2800	4750	5100	5600
C. Total	13610*	3550	5750	6100	6600
D. Foreign exchange component of 'C'	2426	151	1000	1000	1000

**For 1978 (3659); 1979 (4638); 1980 (5313).*

The Company's yearly R&D expenditure has increased from Rs. 36 lakhs in 1978 to Rs. 66 lakhs in 1984.

R&D infrastructure and programmes

The research at UCIL R&D Centre is aimed at development of pesticides suitable for tropical conditions and the facilities, reputed to be among the best in the world, includes three green houses having approximately 2,700 sq. ft. total area and having controlled temperature, humidity and lighting conditions, 5 insect rearing laboratories wherein major rice insect pests are reared and an experimental farm of 2 hectares where experiments to determine residues on tobacco, chilly, cotton, potato, pulses, onion, etc. are in progress. A major R&D project completed at the UCIL R&D Centre is the perfection of mass multiplication and screening techniques for major rice insects such as gallmidge, stemborer, brown plant hopper and green leaf hopper. The R&D Centre is engaged in a big way in studying metabolism and residue of pesticide chemicals (received from the parent company) in soil, water and crops. About 150 new pesticidal molecules have been screened against rice pests during the last six years. For the field experiments the Centre has entered into collaboration with the Indian agricultural universities. The Centre is receiving on a regular basis new pesticidal molecules from the parent company for which residue analysis and bio-efficacy studies are being conducted through agricultural universities and institutes such as IARI, New Delhi, PAU, Ludhiana, HAU, Hissar, TNAU, Coimbatore, CTRI, Rajamundry, CRRI, Cuttack, JNKV, Jabalpur, etc. After conducting field studies and various laboratory experiments, the Centre is sending the data to the parent company in the United States. The UCC R&D laboratories in Bhopal have even exported process design and manufacturing technology for TEMIK and SEVIN and their formulations involving know-how for production of lethal compounds, like MIC and phosgene, respectively to France and Indonesia.

R&D covers grey areas

Now, this extensive co-operation in R&D with the parent firm has been even formalized. Recently, the UCIL R&D laboratories entered into a collaboration agreement with the UCC, USA, to conduct experiments to synthesise new molecules, test them on tropical pests at Bhopal and supply the research data for an annual fee of US $ 300,000. It appears that the UCIL has been conducting field studies using new chemical agents without getting the projects cleared through the high level screening committees of the three Secretaries of which the Secretary of the Ministry of External Affairs and the Defence Adviser are members. The top level committee was set up in 1975 for screening from the security angle all the research projects under collaboration after the PAC report on the Bombay Natural History Society's collaboration with the John Hopkins University to experiment on migratory patterns of birds and genetic control of mosquitoes experiments. The company is conducting also biological research related to identification and collection of germplasm for the rice varieties in the strategic area of North-eastern region of the country.

Expand the probe

It must be noted that this R&D effort covers the grey area between peaceful application and biological warfare. The company has been claiming income tax exemption for this in-house R&D work. It should be stressed here that under the Indian Income Tax laws, such exemptions are confined to the R&D in the line of production. The question arises, whether the production is not a cover for the R&D activities useful to the U.S. Government. The ambitious expansion in R&D and the grey nature of the R&D programmes raises doubts about its real purpose.

The DSF expects the terms of reference of the on-going enquiry to be expanded so as to include these aspects also. There is an essential need for new mechanisms to ensure that the people of this country will never be guinea pigs and subjects to inhuman degradation for purposes of war.

CRISIS MANAGEMENT

IT IS self-evident that even the enactment and enforcement of all the laws do not obviate the need for institutionalized mechanisms to deal with crises, such as the Bhopal tragedy, as and when they occur. Such mechanisms, evolved and implemented with full public participation, would include emergency drills, appropriate medical facilities, public information systems etc. Many important lessons may be learnt from the Bhopal tragedy.

In the total absence of measures to educate the public or to take institutions and the people into confidence, the decision to restart the plant so as to neutralise the remaining methyl isocyanate (MIC) by convering it into pesticide SEVEN were naturally viewed with great apprehension. This resulted in a panic and exodus from the city. The fears were further fed by all sorts of rumours. Coupled with this is the total lack of credibility of the official media, the T.V. and Radio and of official pronouncements. The utter failure of the authorities at the height of the tragedy, the collapse of official mechinery and the poor performance of A.I.R. and Doordarshan shattered the confidence of the public who are already in the grip of panic and confusion. All this is compounded by political gimmickery and the concentration of the official efforts on obtaining compensation from the U.S. company rather than on providing immediate relief and taking pecautionary measures.

The causes and pattern of failure of UCIL plant are yet to be definitively ascertained. The fact, however, remains that the possibility of such an accident should have been anticipated right from the day the plant went into operation. The dimensions of the tragedy in Bhopal show clearly that the Government had no plan to enable to cope with this eventuality. Not only were such measures absent, the official machinery itself fell victim to panic. It is no exaggeration to state that the public acted with greater control and foresight. Much before the official machinery which had earlier fled the city returned to initiate some sembalance of rescue and relief operations, many of the people had on their own stepped in to begin the task. Private vehicles like trucks, rickshaws, etc. were ferrying people away from the worst affected areas and taking victims to the hospitals. It was only such later in the day that official machinery got involved in such operations and even then with no clear-cut plan. Needless to say that such random efforts were limited and handicapped by the total absence of information and instructions as to how to react to such a situation.

On the fateful morning, the A.I.R. made no relevant announcements which could assist the panic stricken people. People fleeing from the worst affeted areas often ran into the wind carrying toxic gases. Even the broadcast schedule of the A.I.R. and Doordarshan did not change till later in the day : when people switched on their sets to get some instructions after the news of the accident had spread, they found to their dismay that the stations were off the air as usual. Even when they did come on the air at the usual time, the tragedy was mentioned only in passing in the regular news bulletin and that was all.

Central coordination of rescue, relief and public information operations was and continues to be glaring by its absence. Till the 11th instant there was no attempt to issue detailed guidelines to practicing physicians spread all over the city. Nor were there any public announcements as to the expected symptoms and possible precautionary and first aid measures. Even today no machinery exists for continuous monitoring of victims discharged from hospitals or for abservation of the delayed effects and rushing in of necessary medical assistance.

Disinformation and Non-information.

The authorities have adopted a curious strategy of withholding vital information regarding the extent and the effects on human beings, birds, animals and vegetation. This has added to the lack of awareness of the general public and other relief personnel, and has contributed to further panic. Even technical personnel, including doctors are being kept in the dark regarding the investigations being conducted and the results obtained

Information is also being withheld from scientists who, while not part of the high powered government team, are highly motivated towards helping the team established, in the area of delayed effects and second order impacts. Much of the information generated is being treated as " classified". Only modified versions, often deleting all the reservations and qualifications attached to the test findings by the investigating team, are being released to the public. Given such limitations and the inadequacy of available equipment, relief measures are naturally achieving only qualified success.

Wind direction data was not made available to the public. Nor were any guidelines available in the hospitals while thousands of victims were pouring in. Even the contents of the toxic emmissions were shrouded in mystery : in the early days after the tragedy it was not known whether the gases were chlorine, carbon monoxide, phosgene, MIC, a mixuture of these or some other gases. Since both cause and possible treatment were not made known, needless to say that some of the drugs administered proved to be ineffective or at times even counter productive. No special instructions or training had been given to local hospital or doctors to deal with the toxic effects of the poisonous gases used in the production processes eversince the plant had been in operation.

Delayed effects, again unanticipated, regarding which no guidelines or instructions were issued are al eady beginning to take their toll. Further, secondary infections have set in the patients who were treated earlier for exposure to the gases. Even today as many as a patient a minute is being admitted to hospitals in Bhopal.

Apart from the total absence of the measures to educate the public as well as medical personnel, which would have greatly amelerioated the condition of the affected population, the authorities confounded the situation with a host of disinformation which only served to creat further panic and hampered relief operations. Within a few days of the accident, presumably on the basis of preliminary investigations, formal statements were issued that air, water, vegetation and food stuffs were safe everywhere in the city. At the same time T.V. features informed people that poultry was unaffected but wanted people not to consume fish, etc. Confusion was rampant and people were asking if it was safe to consume eggs, vegetables, etc.

Before a full assessment had been made, came the official announcement that the factory was being closed and that no further production would take place. No indications were given as to what would be done to the MIC remaining in the plant. The subsequent decision to restart the plant in order to neutralise the MIC, against the background of the prevalent confusion and lack of awareness, led not only to fresh panic but also contributed to the total loss of credibility of all the concerned authorities, their intentions and pronouncements.

The lessons is to be drawn from the above are clear. Lessons may also be drawn from the experience of other countries which, besides having stringent industrial safety laws which are effectively implemented, also have well-planned and constantly reviewed emergency drills and procedures. In the U.S.A. for instance, ironically in West Virginia itself which houses the UCC parent plant, the Environment Protection Agency regularly conducts such drills and reviews, every month, its procedures with wide consultations with all agencies and the citizenry.

LOOKING BEYOND

Points of focus for Enquiry & Action

The report prepared with much haste in the horrifying aftermath of the world's worst industrial accident, is an attempt to focus attention on certain important issues related to our people's safety, the right to know, public policies relating to industrial licencing, foreign collaboration agreements, technology transfer, in house R&D, MNCs operations, effectiveness of existing regulations, laws relating to location of industries, environment and pullution, need for machinery to monitor long-term and medium-term effects, and a host of other issues like the status of occupational health and industrial medicine. Given the paucity of information, literature and also time, the report is amenable to considerable improvement.

Apart from the difficulty of getting across to information and data relating to the incident gathered by the authorities we were like many others handicapped by the non-availability of information and published literature of matters relating to industrial safety, occupational health, industrial medicine. Literature on effects of toxic chemicals, like MIC and phosgene, many of which falling under the grey area having both peaceful as well as warfare implications, is hard to get. As members of the scientific community, we were faced with the sudden reality that scientists were groping in dark about the reaction chemistry, values of heat of reactions, etc. which are crucial for the chemical calculations, various kinds of unclassified reactions and process details.

All this and the hesitancy to take the people and scientific community at large into confidence, has resulted in enormous confusion. An expert team is investigating the Bhopal tragedy. The team is expected, with the resources at its command, to produce a report which is fully informative and with details which could be cross checked independently by other members of the scientific community, including S&T voluntary organisations. One hopes that such a report would be forthcoming and would be freely available.

We hope that the following issues would be covered specifically in the report :

(a) Data related to the symptoms exhibited by the victims of the gas tragedy, and autopsy reports on human beings, cattle as well as aquatic life such as fish must be made available. We have been told that amides and cyanides have been found in large quantities in the bodies of some of the victims. This may be confirmed in the report. We have also been informed that fish, especially fingerlins, died in the neighbourhood. Such evidence would help identify the nature of toxic substances involved in the tragedy and the counter-measures required.

(b) Samples taken from the field (air, water, foodstuffs, etc.) as well as from various parts of the factory are understood to have been sent to various laboratories. The report of the expert committee should reveal fully the method of collection, site of collection, analytical methods adopted as well as results of the analysis and the reasons for conclusions.

(c) A number of questions relating to the nature of toxic gases released, how the reactions began, etc. need to be answered. Details of the calculations regarding the mechanism, reactants, reaction chemistry etc. and the impact area of the toxic emissions should be given.

(d) It is presumed that the expert committee would go into the plant records which the C.B.I. has already seized. Further, it is essential that all documents and data related to inhouse R&D be also made available for critical evaluation by the expert team.

The report should also throw light on the following facts :

(i) Whether the plant handed down to UCIL was obsolete or not ?

(ii) Had it been rejected by others on the basis of dangers involved in undertaking production with the obsolete equipment ?

(iii) Was the transferred know-how package adequate in respect of safety information ?

(iv) Whether it is a fact that the Company was preventing its workers from obtaining adequate information on safety drills and data on the process by the type of practices which it adopted to keep the technical information secret ?

(v) In what all respects did the safety standard incorporated in the design followed by the UCIL differ from the ones followed by the UCC in West Virginia plant of the UCC, USA ?

Full implications of the incident would become apparent only when all these aspects are seen in their interconnections and full scope and brought into the ambit of the enquiry underway.

It is presumed that the expert committee would go into the plant records which the C.B.I. has already seized. All the documents would be necessary for a full scope enquiry into the functioning of the UCIL. It is essential that all documents and data related to in-house R&D be also taken into official custody for critical evaluation by the expert team. The team should examine the hazards and the safety aspects of the R&D activity itself.

The expert committee has also to investigate why in spite of several accidents in UCIL, no monitoring of the safety measures was undertaken.

We hope that all those responsible for this tragedy would be brought to book.

This tragedy has clearly demonstrated the woeful inadequacy of the infrastructure in our country pertaining to industrial safety and occupational health. It is not enough for India to claim to posses the third largest scientific and technical manpower in the world. Scientists, engineers and technologists should all join hands with workers, doctors, lawyers and teachers to overcome the existing apathy in this crucial area.

Whatever one may expect of the Government and irrespective of what the government and related agencies may actually acheive by way of legislation and executive measures to tackle the whole problem of industrial safety, it is only the vigilance of the people at large and the scientific community in particular, which can guarantee safe harnessing of science and technology for human welfare. The scientific community must play an important role in building and spreading the awareness of the potential hazards and the measures that are required to counter them.

Appendix-1

Organic Isocyanates

Organic isocyanates are compounds in which the isocyanate group - N = C = O, is attached to an organic group. They are frequently classified as esters of isocyanic acid HNCO. Isocyanates represent a reactive class of compounds since the isocyanate group (- NCO) reacts with a wide range of compounds as well as with itself to form dimers, trimers polymers and carbodiimides.

The normal isocyanate reaction ultimately provides addition to the carbon-nitrogen double bond. In reactions involving compounds with an active hydrogen, i.e. one that can be replaced by sodium, the hydrogen becomes attached to the nitrogen of the isocyanate, and the remainder of the active hydrogen compound becomes attached to the carbonyl carbon :

$$RN{=}C{=}O + HA \rightarrow RNH\overset{\overset{O}{\|}}{C}A$$

All reactions are catalysed by acids and, usually, more strongly by bases. Certain metal compounds are exceptionally powerful catalysts.

Most compounds that contain a hydrogen atom bonded to oxygen react with isocyanates under proper conditions. Isocyanates are hydrolysed rapidly by water and give the corresponding disubstituted urea :

$$RNCO + H_2O \rightarrow RNHCOOH \rightarrow \underset{\text{(amine)}}{RNH_2} + CO_2$$

$$RNH_2 + RNCO \rightarrow RNHCONHR$$

Essentially all compounds containing hydrogen attached to nitrogen are reactive

$$RNCO + HN\begin{matrix} R' \\ R'' \end{matrix} \longrightarrow RNHCON\begin{matrix} R' \\ R'' \end{matrix}$$

Because isocyanates are highly reactive towards such a large number of active hydrogen compounds, more than one reaction may occur in a system at a given time. This possibility is very pronounced in the presence of catalysts.

The reaction of an isocyanate and urea results in the formation of biurets :

$$RNCO + R'\,NHCONHR'' \longrightarrow R\,\underset{\displaystyle CONHR''}{\underset{|}{NCONHR'}}$$

Methyl isocyanate in the presence of nitrates or nitrates in water can give rise to Nitrosoamines which are carcinogenic :

$$CH_3\ NH_2 \xrightarrow[\text{nitrite}]{\text{nitrate}} \underset{\text{(Nitrosoamine)}}{CH_3\ NHNO} \longrightarrow \underset{\text{(diazohyroxide)}}{CH_3NNOH}$$

$$\downarrow$$

$$\underset{\text{(methylalcohol)}}{CH_3\ OH} + N_2$$

Self Addition : These reactions result in the formation of dimers, trimers polymers and carbodiimides. While the aromatic isocyanates are readily dimerised, the aliphalic isocyanates do not easily form dimers. Both alphatic and aromatic isocyanates readily form trimers. The trimerisation of alphatic isocyanates is catalysed by heat and by trialkyl phosphines. Alkaline salts of carboxylic acid, e.g. potasium acetate and many metal compounds that are soluble in organic media, catalyse trimersation. Trimerisation can occur in polymer reactions. It is known that under certain conditions, metallic sodium acts as a catalysist for polymerisation at temperatures well below '0 °C.

Other Reactions : A number of reactions of the isocyanates may be considered to parallel those of the structurally similar ketones, with the exception that the resulting four-membered ring is unstable and opens with the elimination of carbon dioxide. On standing, at room temperature, isocyanates may undergo trimerisation and polymerisation. These side reactions and the hazard of CO_2 formation indicate that MIC should not be kept stagnant without continuous chilling. Exposure to moisture leads to formation of carbon dioxide and the development of pressure in closed containers.

Physical Properties of MIC

Molecular weight	57.05
Specific gravity	0.96 (20°C)
Boiling point	39.1°C
Flash point	-6°C

Toxicology : Methyl isocyanate is an irritant of the eyes, mucous membranes, and skin; it can cause pulmonary irritation and sensitization. Exposure may be either through inhalation or skin absorption. Exposure of humans to high concentrations causes cough, dyspnea, increased sensitization in susceptible individuals; should this occur, further exposure should be avoided, since even extremely low levels of exposure may trigger an asthmatic episode; cross sensitization to unrelated materials probably does not occur. Experimental exposure of four human subjects for one to five minutes caused the following effects : 0.4 ppm, no effects; 2 ppm, lacrimation, irritation of the nose and throat; 4 ppm, symptoms of irritation more marked; 21 ppm, unbearable irritation of eyes, nose and throat.

The rats exposed for four hours, the LD_{50} was 5 ppm; effects were injury to the lungs and subsequent pulmonary oedema. A cotton plug saturated with the liquid was applied to the ear of a rabbit for 30 minutes caused erythema, oedema, necrosis and perforation; a few drops on the ear of a rabbit caused destruction of tissues. The liquid contact with the eye may cause permanent damage.

The TLV (0.02 ppm) was set at a level to prevent irritation to mucous membranes.

Diagnosis : Signs and symptoms include irritation of eyes, nose and throat; cough, increased secretions, chest pain, dyspnea; asthmatic episode; injury to eyes and skin from splashes. By analogy with effects caused in animals, it may cause pulmonary oedema.

Differential Diagnosis : In mild exposure resulting in mucous membrane irritation, the symptoms may mimic a viral upper respiratory tract infection. The latter may be characterised by fever, myalgias and lymphocytosis.

Uses : First organic isocyanate was prepared in 1849, but these compounds became commercially important after World War II. Mono isocyanates are used for modification of organic compounds while di and poly isocyanates find extensive application in the polymer industry. Among the several alphatic isocyanates of commercial significance, Methyl isocyanate (CH_3 NCO), is used in the manufacture of several insecticides and herbicides.

Sevin or Carbaryl : In a search for new insecticides, a large number of aryl esters of methyl carbamic acid have been synthesised with phenols as a starting point. Only a limited number of these are used in agriculture including such compounds as carbaryl (SEVIN), Zectran, Mesurol, etc. The chemical composition of SEVIN (1-Naphthyl N-methyl carbamate) is

O CO. NH. CH_3

SEVIN was introduced by UCC in 1956. It is considered to be biodegradable. However, the range of mamalian toxicity of carbamate insecticides like SEVIN is great. SEVIN is only less toxic than aldicarb or TEMIK (2-methyl-2-(methylthio) propionaldehyde-o-(methyl carbamoyl) oxime, one of the most actuately toxic pesticides in use. In 1976, it was placed in the Environmental Protection Agency (USA)'s list of compounds that are "possibly too hazardous to man or the environment".

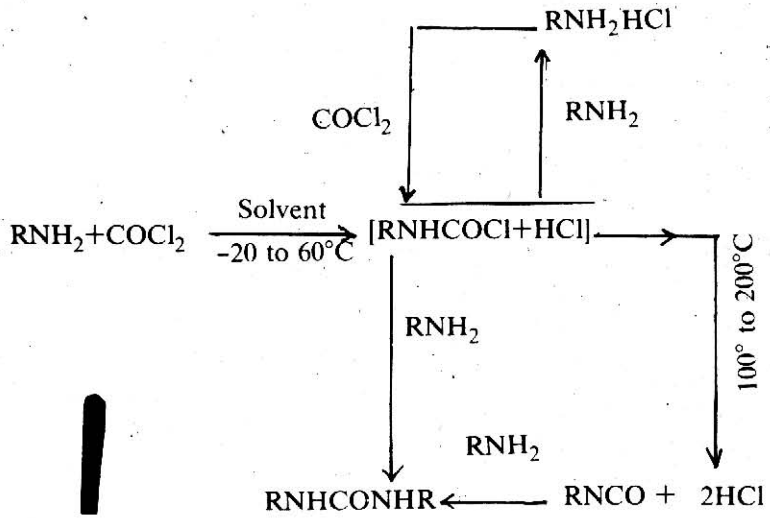
Sevin is recognised as one of the seven human teratogens (i.e. capable of causing genetic defects and birth of malformed children) by the Mrak Commission's Panel on Teratogenesis (US Department of Health, Education and Welfare). Tests on animals have shown sevin to be careinogenic. It is a contact and stomach pesticide used for control of codling, tortrix, and winter moth caterpillers, capsids and earings in apples, against pea moth, etc.

Appendix-2

Manufacture of MIC and SEVIN

The reaction of amines with phosgene (phosgenation) has, for economic reasons, been used almost exclusively for the manufacture of isocyanates. The details of processing may vary with specific isocyanate and, in particular, for aromatic and alphatic isocyanates, but the general approach is the same. The processes used in the manufacture vary in many details and the several multinational corporations hold patents for the different processes used. For example, the UCC itself holds a patent for production of Sevin without storing MIC. However, the UCIL, Bhopal uses a process which involves, first the production and storage of MIC and then, in the second step, manufacture of different MIC based pesticides like Sevin using the stored MIC.

The primary reactions involved in the phosgenation of a simple amine are indicated below :



RHN_2-Simple amine, R stands for the aromatic or aliphatic group. For the production of MIC, Methyl amine, CH_3NH_2 is used.

Commercial production of organic isocyanates uses the following general scheme :

(1) The simple amine is dissolved in a suitable solvent such as Chloroform, Xylene, mono-cholorobenzene or orthene (0-dichlorobenzene) and is allowed to react with a solution of phosgene in the same solvent at a temperature below 60°C.

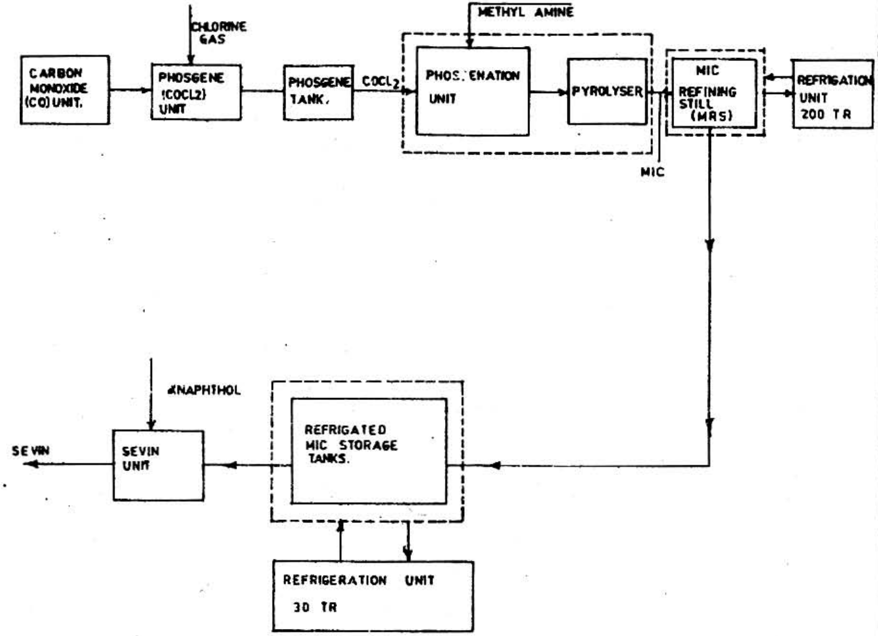
(2) The resulting reaction mixture slurry is then digested in one to three stages for several hours at progressively increasing temperatures upto 200°C with the injection of additional phosgene; and

(3) The final solution of reaction products is fractionated to recover hydrogen chloride, unreacted phosgene and solvent for recycling and waste disposal; isocyanate is collected and the residues are incinerated.

Note on Abbreviations Used.

Threshold Limit Valve (TLV). TLV is by definition the permissible concentration levels of toxic substances in the atmosphere of the workplace, for a 8-hour working day, five days a week. They are limits designed to control atmospheric contamination. However, due to wide variation in individual susceptibility, a small percentage of workers may experience discomfort from some substances at concentrations at or below the TLV; a smaller percentage may be affected more seriously by aggravation of pre-existing conditions or by development of occupational illness. The TLV do not necessarily take into account long-term effects.

Lethal Dose 50 (LD_{50}). The LD_{50} test determines the dose at which 50 percent of the animals treated die. The test was introduced in 1927. Though the LD_{50} test is meant to measure acute toxicity of a substance or the harmful effects of a single dose, most toxicologists now believe that this test has largely outlived its usefulness.



PROCESS FLOW DGM FOR SEVIN.

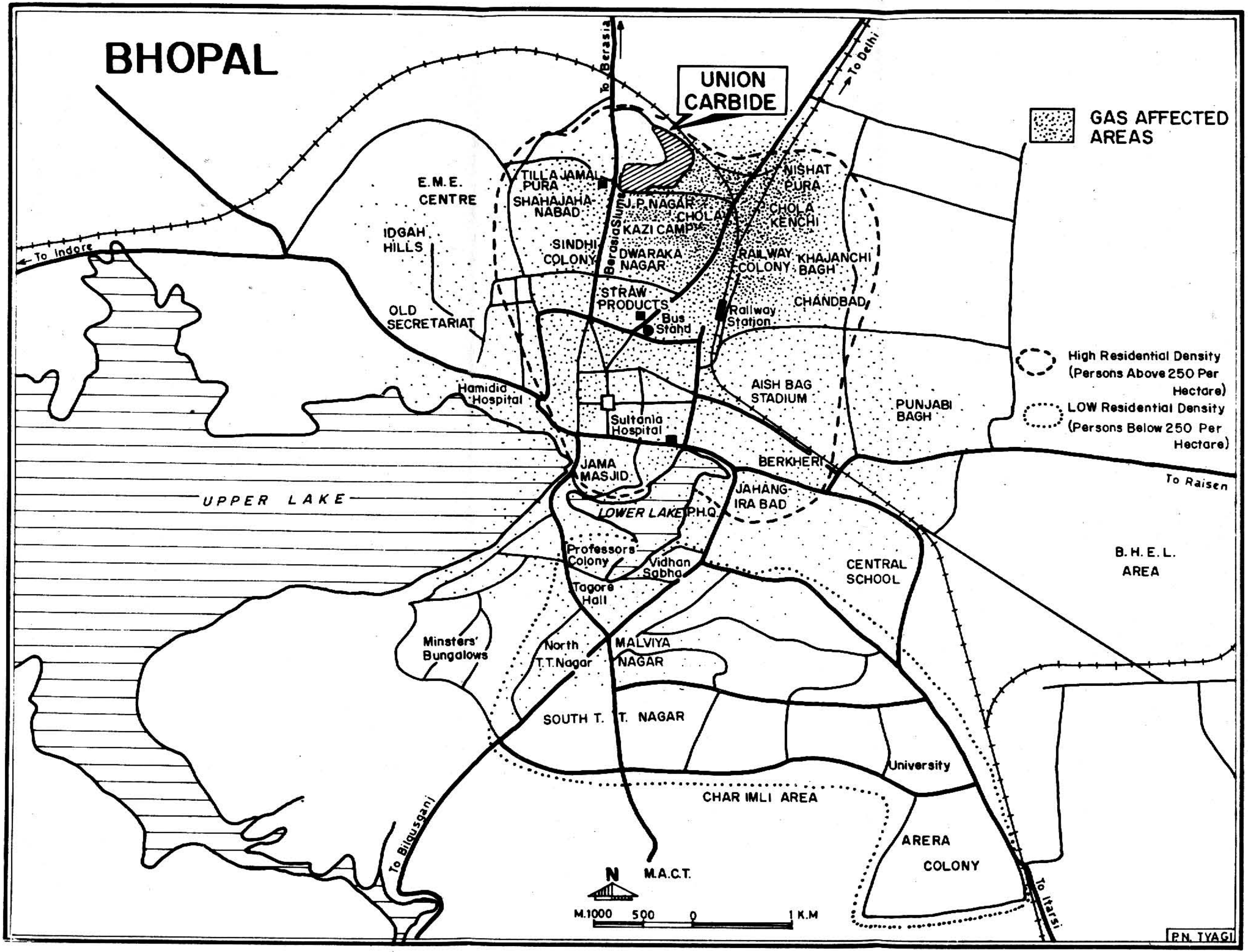
Summary of Catalysts* Promoting various Isocyanate Reaction (S)

Amines	Alcohols	Water	Carboxylic acids	Ureas	Urethans	Phenols	Trimerization	Dimerization†
triethylene-diamine	Bi cpds	triethylene-diamine	Co cpds	Sn cpds	Pb cpds	tertiary	strong bases	phosphines
Pb cpds	Pb cpds	tertiary amines	Fe cpds	triethylene-diamine	Co cpis	amines	and basic	tertiary
Sn cpds	Sn cpds	Sn cpds	Mn cpds	Zn cpds	Zn cpds	ZnCl	salts	amines
Co cpds	triethy-lenedia-mine		trethylene-diamine	Zn cpds	Cu cpds	basic salts	Pb cpds	(in high concn)
Zn cpds	Ti cpds		tertiary amines		Mn cpds	$AlCl_3$	Co cpds	
ureas	Fe cpds		CH_3COOK		Fe cpds	acids	Fe cpds	
tertiary amines	Sb cpds				Cd cpds		Cd cpds	
carboxylic acids	U cpds				V cpds		V cpds	
	Cd cpds						tertiary amine plus alcohol.	
	Co cpds							
	Th cpds							
	Al cpds							
	Hg cpds							
	Zn cpds							
	Ni cpds							
	tertiary amines							
	V cpds							
	Ce cpds							
	MgO							
	BaO							
	pyrones							
	lactams							
	acids							

*Catalysts that promote reaction with the active-hydrogen compound shown.

†For aromatic isocyanates only.

(*Source*: Encylopedia of Chemical Technology. Vol.21.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To Berasia
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