Methods for Assessing and Reducing Injury from Chemical Accidents
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# 16 *Factors Affecting the Occurrence and Initial Management of Chemical Accidents*

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## 16.1 INTRODUCTION

The advances in chemical synthesis and chemical engineering design together with the development of sensory and analytical instruments have resulted in the production of a very large number of basic chemicals, intermediates and final products. These include inorganic chemicals, organic chemicals, intermediate products as well as polymers. The variety of chemicals in production exceeds 70 000. The total number of chemical species made in the laboratory and listed in *Chemical Abstracts* to date exceeds 6 million and from time to time, some of these enter manufacture, transport and trade and reach the consumer.

World production of chemicals of all types is in excess of several tens of millions of tonnes per annum. The production volume increases by 10% to 15% per annum to meet world needs. As demand increases, the sizes of production units are enlarged to maintain or lower costs of production by economies of scale. New units for manufacture are also being established all over the world, often in new locations. These are also transported by road, rail, boats, ships and even by air. They are stored in large volumes in factories, distribution points, ports and at consuming locations. The periods of storage and the conditions of storage also vary widely and are often influenced by changes in market demand, shipping schedules, loading and unloading facilities, availability of packaging, containers and dedicated wagons, customs clearance, insurance, finance and weather conditions.

Unintended leakage may occur from storage or materials in process or in transport due to a variety of causes. The systems for eliminating or minimizing chances of leakage and further containment and obtaining the least damage depend on the fullest appreciation of the physical, chemical and toxicological properties of the materials as well as anticipation of hazards that may arise. The design of systems and of training of all those involved together with disclosure of information to the regulatory authorities and the public on the nature of hazards are essential elements for avoiding the unintended release of materials and for subsequent management.

## 16.2 PLANNING TO AVOID THE OCCURRENCE OF ACCIDENTS

In order to evolve systems and procedures to meet eventualities, the following have to be taken note of:

- *Nature of material* Solid, liquid, gas, and the conditions for conversion of solid to liquid and liquid to gas. Latent heats of melting and vaporization. Specific heats.
- *Flammability* Flash point; explosive character in presence of air or oxygen or in their absence. Heat of combustion.
- *Solubility* In water, solvents and partial vapour pressure in air at different temperatures.
- *Reactivity* With metals in presence of water or air or both; with water, alkali or acid. Capacity for polymerization. Initiators of polymerization. Nature of products of reaction, heats of reaction. Stability and reactivity of products on heating and formation of additional products including gases. Reactions which may occur due to exposure to sunlight and the products of such reaction. Solubility of reaction products in water, organic solvents, edible oils and their absorption on soil or other surfaces.
- *Stability* The stability of the chemical or its reaction products in the environment on exposure to air, moisture, sunlight.
- *Toxicity* Toxicity at different concentrations to man, animals, birds, fish, flora. Inhalation toxicity. Ingestion toxicity. Contact effects on exposure. Teratogenicity. Mutagenicity. Abortifacient effects. Excretion rates in man and animals in urine, faeces, milk. Neuromuscular effects. Acute and chronic toxicity. Retention data as in the case of halogenated aromatics. Allergenic effects. Immune suppression potential. Sex linked effects. Carcinogenic properties.
- *Metabolism* Metabolic pathways of the chemical and its reaction products in man and different species of animals and plants.
- *Special effects* Synergestic effects, effects in different age groups, effects in pregnancy, undernourished persons or those with some impairment of normal functions or suffering from illness. Absorption through open injuries or through skin should also be taken note of.
- *Short- and long-term contamination sources* Water supply sources, stored food grains and food articles. Absorption from soil into food crops, animal feeds, food chain.
- *Other unusual effects* Temporary, semi-permanent and permanent sterility in man and animals. Preferential destruction of micro-organisms, natural

predators, leading to changes in ecological balance. Drug and pesticide resistance.

A measure of knowledge and information on the above is necessary for design of safety systems in storage, manufacture, transport and distribution in order, firstly, to incorporate adequate degrees of design, controls and training and, secondly, to devise steps to minimize the extent of damage in the event of spillage, leakage and release. In the choice and location of various facilities and controls, it is essential to pay attention to the following factors.

### 16.2.1 Site for Manufacture

In the case of large-scale manufacture of highly flammable and potentially explosive products or materials which can have effects on life systems, the facilities for storage or production should be located well away from centres of high population density. There should be adequate land area to allow for expansion and diversification. The area should be fenced. It is desirable to have a green belt or open area around, free from habitation. This is particularly applicable to manufacture of petroleum products, petrochemical intermediates such as olefins and aromatics, ethylene oxide, phenols, caprolactam, acrylonitrile, vinylchloride, epichlorhydrin, acrylic esters, aliphatic dienes, hydro aromatics, organic isocyanates, chlorinated and nitrated aromatics, nitro-paraffins, nitro-glycerine, amines, nitrates, alkylating agents such as alkyl halides, mercaptans, methanol, formaldehyde, aliphatic and aromatic aldehydes, acid chlorides, anhydrides and mustard gas derivatives. Similarly, the production of polymers involving high pressure exothermic reactions and oxidation products such as caprolactam, terephthalic acid, phthalic anhydride and phenol from exothermic reactions, requires much care in selection of sites. In other cases, use of oleum, chlorine, nitrous oxide, hydrofluoric acid, fuming nitric acid, fluorine, bromine also requires much care. Hydrogen storage and application also involve high risks of explosion as also use of carbon monoxide, phosgene, hydrogen cyanide, ammonium nitrate and hydrogen sulphide. Similar precautions are necessary in the siting of units for production of ammonia, biologically active drugs, antibiotics, pesticides, adhesive components, agricultural chemicals, herbicides, hormones, steroids, animal and human vaccines and oral contraceptives. In each case, the extent of potential explosion, leakage, and contamination of air and water bodies should be taken note of in selecting sites.

### 16.2.2 Layout and Plot Plan

The siting of plants and utilities should be based on certain basic guidelines and no compromises should be permitted. The approval of experienced plant managers, chemists, chemical engineers, safety officers, occupational health officers, engineering design personnel should be formally obtained. Records of issues raised and resolved with full account of the specific problems posed by named individuals should be maintained together with the names of those who had access to these and provided final approvals. These are valuable documents for corrections in the event of minor accidents and for future expansion and diversification.

The guidelines should cover the following:

- Minimum distance from periphery.
- Entry–exit courses in emergencies.
- Entry of non-plant personnel, trucks, railway wagons, sales, marketing, finance divisions, location of points for delivery of raw materials, spares, packaging.
- Access to units of storage or of processing of flammable, explosive, hazardous toxic materials for fire fighting or containment.
- Plant operations instruments and control room, plant quality control facilities to be situated and designed to protect them from blasts, fire or toxic fumes, so that personnel in these areas could take actions during emergency and subsequent investigations.
- Water storage for fire fighting, lines to be located from blast areas overground or underground or both. Pipelines and electrical cables to be laid in concrete trenches underground with loose concrete block covers.
- Main power station and emergency power facilities, fire tender stations to be located at safe distances.
- Adequate separation between individual plants, storage, in multi-unit multi-product complex. Adequate space to be provided for addition, expansion in individual plants.
- Multiple fire hydrants with alternative water supply lines underground.
- Communications centre, telephone exchange, wireless, plant loudspeaker systems, general alarms to be located for operations in emergencies.
- First aid, medical centre facilities to be available away from main plant, near entry gate.
- Loading bays, parking of vehicles, railway wagons to be well away so that accidents in such areas do not have spread effects.
- Water flooding in emergency to be allowed to flow freely in large drains to a designated pool to prevent contamination of public access areas.
- Each major plant unit to be isolated with easily removable fencing to ensure factory personnel authorized specially for entry into each area to gain access during normal operations.
- Special facilities for destruction and disposal of hazardous materials which are unstable or in excess of designated levels for processing. This may arise from shutdown of downstream units or during stoppage of transport.
- Air supply for air conditioning in control rooms, administrative offices, quality control rooms, medical centre and such areas for actions in emergen-

cies to be provided from locations well outside the plant and hazard area to ensure toxic fumes are avoided. Plant nitrogen or air system for instrument operation or for ensuring inert gas cover in specific cases should be so located as to be safe and reliable to avoid one accident triggering many more.

- Alarm and communication facilities from plant to civic authorities should be located at the furthest point from plants and should be protected for operation even in the case of toxic leakages.
- Special equipment for handling harmful materials such as pressurized suits, breathing apparatus, gas masks, gloves, gum boots, plastic wear and special tools should be located at several points for access and especially in control rooms and plant offices.

### 16.2.3 Design for Safety

While layout and plot plan are the basic features for safety and containment in accidents, the detailed engineering practices should incorporate a number of features for safe operation, safe shutdown and post-accident actions. Important among these are listed below:

- The team for basic engineering package and process and instrumentation review in a chemical plant should include experienced specialists already mentioned and should further include instrument engineers, analysts, computer scientist, training manager, corrosion and maintenance engineers.
- Instrumentation for hazardous operations should be exhaustive and there should be duplicate measuring equipment and on-line analytical equipment. Automatic controls should be backed by manual controls for situations in which there is failure of automation. Vapour detectors, smoke detectors, level, temperature, pressure, flow recorders should be provided with redundancy to allow for maintenance and repairs. Multiple measurements should replace single ones and for highly reactive exothermic systems, such as polymerization, acylation, oxidation, hydration, steam reforming, oleum dilution, ammoxidation, nitration. Continuous computation from multiple parameters is essential for detecting high heat formation and runaway reaction potential. Heat removal systems in these cases should have redundancy of pumps, valves and rupture discs together with automatic cut-off of reactant supply. Catalytic reactions develop heat points and zones even when bulk material temperature is not abnormal and suitable instrumentation must be provided for early detection.
- For volatile liquids and gases, such as chlorine, sulphur and nitrogen oxides, hydrogen cyanide, hydrogen sulphide, fluorine, bromine, chloro-paraffins and olefins, hydrogen flouride, ethylene/propylene oxide, phosgene, carbon monoxide, isocyanates, mercaptans, detectors should be installed in a number of locations with alarms in control rooms. For all hazards, in addition to visible detectors, sound alarms should also be installed.

- In the case of corrosive, lachrymatory or toxic solids and liquids, storage areas should be isolated with appropriate systems to deal with leakages.
- Intermediates which are volatile and which may be toxic or readily polymerizable or both, should not be stored in excessive quantities. These include carbon monoxide, phosgene, epichlorohydrin monomer, sulphur dioxide, sulphur trioxide, nitrogen oxides, hydrogen sulphide, alkyl isocyanates, peroxides and mercaptans. Containers for these should be of small sizes so that even in the case of accidental leakage, material released will be a small amount. Storage of large quantities in single tanks should be totally avoided.
- For materials stored with refrigeration, spare refrigeration facilities should be provided together with emergency power as well as systems for safe disposal in the case of failure of refrigeration.
- Water is ubiquitous in chemical plants. For those chemicals which react violently with water, a very high level of precautions should be taken in design to avoid any possibility of contact with water. Cooling of such materials in distillation or storage should be through inert sealed liquid circulation which is independently cooled by water by double heat exchangers.
- Similarly, for materials which react with air and oxygen readily, pumps should be covered under inert gas.
- Process and instrumentation review and detailed engineering review proceedings should be recorded in a summary form for ready reference in the future.
- Manuals of operation including actions for emergencies should be prepared and be readily available to plant personnel. Training should be carried out with simulators and should include thorough familiarity with emergency operations. Periodic retraining is necessary. Transfers of personnel from one plant to another should be made after training, testing and certification.

### 16.2.4 Operations

Successful safe operation of plants depends on the strict adherence to the guidelines outlined for layout/plot plan and design, engineering and construction to specifications, followed by pre-commissioning checks. Adequate facilities for maintenance, repair and replacement should be provided. A high degree of importance should be attached to periodic shutdown and examination, planned checks for corrosion, pressure vessels, safety and fire drills and periodic unannounced checks for preparedness for emergency operations are all necessary to minimize chances of accidents. The following additional measures are also essential:

- Changes in plant, pipelines, controls, instrumentation should be made by written proposals, reviews and approvals.

- Removal of any controls, refrigeration or resetting of limits should normally not be allowed unless they are for increased safety and are carried out by review approval procedures.
- All leakages, unanticipated process conditions, failures of utilities, however minor, should be reported to high level. Information on leakages should be reported to civil authorities. Small faults and indications of abnormality, if properly investigated and remedial steps taken, would in most cases, prevent major mishaps.
- Storage of hazardous materials in excess of planned quantities should be totally avoided. In any case, specific approvals from designated higher level authorities should be formally obtained.
- Operation manuals and training should record actions for utility failure such as power, water, air, inert gas, nitrogen, refrigeration, flare system, vent gas absorption, effluent treatment, drainage, cooling tower, steam or emergency power. Probability of accident increases by multiplication of failures of systems.
- Minimum trained staff at all levels especially in shifts should be specified. Adequate cover for absence on leave or sickness should be provided. Operations should be stopped when staff are below levels. Working continuously for more than one shift by personnel should be extremely exceptional.
- Maintenance and repairs should be carried out with safety permits normally during daylight hours under supervision. Alterations to plants and additions should be made with care, preferably during shutdown. Excessive employment of temporary staff or contractors for routine maintenance of plant should be avoided.
- Quality control standards as well as maintenance of records on operations and reporting of abnormalities should be without exception. No material should be transferred to storage or next stage in each batch or shift without quality certification.
- Alteration of analytical procedures should be formally proposed, reviewed and approved.
- Loading for transport in bulk or in containers should be strictly followed according to recorded procedures which include inspection, cleaning, drying of containers, transfer pipelines. Re-use of drums, containers, cylinders, pressure vessels should have rigorous inspection procedures to avoid leakage or mixing with contaminants.

### 16.2.5 Transport and Storage Outside Manufacturing Unit

Whereas plant operations are generally controlled by experienced staff, transport of hazardous materials and storage at distribution points is carried out by staff who have little knowledge of the properties and hazards of materials involved. Road and rail accidents as well as leakage from improper handling in ports and ships are serious flaws and are causes of many accidents. Specially dedicated wagons, lorries and trained staff should be employed for hazardous materials. This is the case for highly flammable low boiling liquids, such as LPG, propylene, butadiene, potentially explosive materials such as ethylene oxide and toxic materials such as pesticides. Hazardous materials such as oleum, liquid alkali, nitric acid, chlorine, hydrogen fluoride require considerably greater care than normally bestowed at present.

Dependent on conditions, trained staff to deal with emergencies should travel with goods. Pilot vehicles should precede lorries to minimize accidents. Equipment for handling leakages should be provided in the vehicles. Labelling, warning lights and signals should pronounce clearly the existence of hazard. It may be necessary to revise guidelines for transport and labelling.

Similar guidelines apply to storage of materials for distribution. The location of such storage depots and warehouses should receive the same attention as factories. If nearby population increases, storage has to be shifted to new locations.

## 16.3 PREPAREDNESS FOR EVENTUALITIES

### 16.3.1 Information to the Public

A large amount of damage may be caused through non-disclosure of information and publicity on potential hazards. Civic authorities such as government and municipal statutory factory authorities, others concerned with fire fighting, environment, health, water supply, town planning, pressure vessels, explosives, labour welfare and public transport should be fully briefed from time to time. Educational, university and scientific research institutions and hospitals in the neighbourhood of factories, storage depots and highways should be informed of the nature of hazards and of containment, remedial and therapeutic measures.

Employees and families in residential colonies close to factories should be provided with written material for measures in the case of accidents. Periodic demonstration and drills will enhance capabilities for minimizing effects in the event of accidents.

### 16.3.2 Hazard Control Centres

It is well known that petroleum refineries and chemical units tend to cluster in an area and grow. Whole estates of several hundreds of acres are occupied by such units. In these cases, accidents in one unit have potential to cause a chain of events. It is highly desirable to establish in such huge complexes and estates, a common civic control centre to be manned round the clock and equipped with excellent integrated communication systems. A certain schedule of predetermined information should be transferred regularly from each constituent unit to the hazard control centre. It should have a set of staff to take steps to prevent spread of materials and fire and to provide immediate actions in the event of accidents. It should have a list of hospitals, doctors, civic and police authorities and should be able to contact them and mobilize their services. A trained marshal should be called to assume charge from a list of volunteers drawn from the factory units. In special circumstances, it would be necessary to call reserve or regular armed forces for assistance in the event of disasters of large magnitude. Radio and television stations should also be given correct information on the nature of the accident and of precautions to be observed by the public.

The control centres should have available with them a minimum of transport vehicles, stretchers, special clothing and equipment for dealing with flammable, toxic and irritant materials. Wireless communication and emergency power as well as portable battery-operated lights are essential. A committee for the management of the centre should be formed from units in the area and civic authorities and should receive information on additions and alterations in plant and review the facilities and management for actions after accidents. Such a centre can be very valuable in the event of natural calamities such as cyclones, floods, lightning, total grid power failure or in the event of unanticipated problems from traffic jams, railway and road accidents, breakdowns of law and order, wars, epidemics, contamination of water supplies from outside sources.

### 16.3.3 Coordination of Medical Treatment

In the preceding sections, references have been made to the potential hazards from chemical manufacturing and distribution operations and the precautions necessary to avoid such accidents and to minimize the extent of effects of such accidents. Despite these, accidents do occur and produce suffering and damage to unnecessarily excessive degrees. In order to manage the event immediately, it is useful to list the type of damage and injury from chemical accidents. These are: burns from fire; chemical burns from corrosive materials; severe damage to limbs from explosion, followed by fire; damage from inhalation of corrosive or toxic vapours; damage from contact with materials such as oleum, nitric acid; damage to eyes, throat, lungs from exposure; accidental ingestion of chemicals such as pesticides, ingestion of contaminated food, water; prolonged effects from accidental inhalation or ingestion or surface contact; damage to crops, flora, fauna, soil from release of materials.

In the event of exposure to irritant toxic constituents, carried through air, the numbers affected can be very large. In such an event the magnitude of relief operations is colossal. The problems of confusion, anxiety and fear, and loss of contact with relatives creates chaos. Taxi, bus and ambulance services are disrupted due to incapacitation of drivers and operating personnel and in some cases telephone/telex exchange operators. It is essential to bring from outside the area, personnel for manning all civic services as local personnel will be grossly inadequate. Major requirements are for medical personnel from outside the area.

In the absence of authentic information on the nature of gas leakage and appropriate treatment for a variety of symptoms, diagnosis and therapy are made by individual doctors. Treatments tend to be very varied. Therefore, the establishment of a *coordination cell* with high quality physicians, surgeons, medical researchers, toxicologists, biochemical analysts to be set up immediately after an accident should be included in the preparedness plans. This cell should provide guidance and advice to hospitals and doctors on the types of treatment to be provided. There is also a likelihood of the patient seeking treatment from several doctors and being administered different or excessive amounts of medication. In case of undernourished or those suffering from ailments already, there are severe complications in diagnosis to separate inherent illness from effects of exposure. These problems of treatment persist for long periods, even for months leading to controversy and loss of confidence in the medical treatment. Central coordination and the application of the best known systems of diagnosis and treatment by careful scientific observation and analysis can reduce uncertainties and improve relief.

### 16.3.4 Coordination of Civic Services

As in the case of natural disasters from cyclones, earthquakes, floods affecting large areas, in the event of a major gaseous chemical leakage, it is most essential to plan for a *central authority* and *coordination group* to ensure restoration of communication, transport, water and food supply, shelter, clothing, beds and blankets, medical supplies, and to manage exodus and ingress of population. Information centres at different locations, connected to and controlled by the central group can have very large beneficial effects. In the case of major disasters, resulting in death of animals and human beings, the removal of bodies, their identification, examination and disposal are stupendous tasks. Delays may lead to the emergence of epidemics and contamination of water and food supplies. Sanitation and hygiene require utmost attention. Potable water and special containers have to be distributed by tank lorries.

## 16.4 MANAGEMENT OF EVENTS

The degree of success in the initial management of events following a chemical accident depends very largely on the knowledge of materials and systems and on the preparedness for dealing with such events. The details for preparedness have been discussed in the earlier sections in this chapter. Steps to be taken immediately depend on the nature of accident, the types of operations, volume and nature of materials in storage and in process, and the extent of initial damage and the amount of leakage of material. Actions to be taken are listed below in relation to types of events.

### 16.4.1 Fire

Fire of all flammable non-toxic materials has to be dealt with by established fire-fighting techniques. In a chemical plant, however, it is necessary to pay specific attention to avoid heat or fire spreading to toxic materials or to start release of corrosive chemicals. Particular attention has to be paid to safeguarding pipelines containing chemicals. Use of water jets and sprays should in no case lead to contact of water with chemicals reacting violently with water, such as oleum, anhydrides, sodium, magnesium, solid alkali, soda ash. Similarly it should not lead to dissolving of water-soluble toxic substances such as pesticides, antibiotics, drugs; water absorption by detergents and surfactants will produce highly slippery conditions and foams. Excessive water flooding of tanks may displace organic solents and materials which have a specific gravity lower than that of water. These may spread onto the factory floor and into drains and ponds. There have been cases of fumes of sulphuric acid spreading over a city through inadvertent application of water jet on leaked oleum from tanks.

### 16.4.2 Explosion

Chemical reactions lead sometimes to major explosions. The uncontrolled oxidation of cyclohexane, ethylene or polymerization has resulted in major explosions and release of organic materials. Ethylene oxide forms explosive mixtures in almost all proportions with air. Explosive reaction in gas phase polymerization releases ethylene and carbonized polymer. Uncontrolled ammoxidation of propylene may release hydrogen cyanide, acrylonitrile, acetonitrile, ammonia and other toxic materials. Violent reactions in steam reforming may release carbon monoxide.

In the case of explosions, it is necessary to see if any toxic materials is involved. Explosions tend to damage other plants and storage vessels in the vicinity and may release toxic materials. Explosions also tend to start major fires. In multi-product units, there are several dangers and actions should be initiated to gauge and limit damage to other plants and leakages.

### 16.4.3 Violent Chemical Reactions

The types of heat producing runaway reactions have been already discussed. In case they release toxic materials, many actions are immediately required. This would be the case for sulphur dioxide and trioxide, nitrogen oxides, hydrogen cyanide, vinyl chloride monomer, acrylonitrile, benzene, chlorine, bromine, hydrogen, fluorides, isocyanates, phosgene. The supply of reactants to the reaction vessel should be cut off immediately. Alarms should be sounded immediately for general alert. All personnel should move in the upwind direction to avoid inhalation. Where possible, gas masks, breathing apparatus and protective suits should be put on. Information should be relayed to control rooms, area control centres and civic authorities. Emergency lighting and power supply should be brought on in case of power failure. Depending on the extent of leakage and based on knowledge of the nature of materials which might have leaked to the atmosphere, predetermined communication should be sent. Wind direction and velocity are major factors in spread and populations downwind should be alerted. If the senior supervisor has been involved and is incapacitated, the next senior should assume command and direct operations. Plant communication system should be used to avoid panic and confusion. Public authorities should be kept fully informed so that they can provide authentic information to the public on actions. It is essential to counteract rumours and false information. Relatives of plant personnel should be informed. Public should be directed not to move towards the plant area. Large numbers of police, journalists and public gathering near the factory or depot may lead to difficulties in providing first aid and relief to those affected. Traffic should be diverted. Medical assistance and ambulances should be called in and provided with known information on toxic effects and remedies.

Atmospheric alteration has a profound effect on dispersion. Meteorological offices should be contacted for weather data and for forecasts. Hospitals in the neighbourhood should be alerted to receive injured and those affected.

### 16.4.4 Release of Liquids into Air

Chemical agents which are low boiling liquids, on leakage condense on to floor and surfaces. Depending on atmospheric conditions they evaporate slowly. The air may contain toxic or irritant materials for prolonged periods. These should be estimated and information provided.

With suitable sensors, the concentration of such materials in the atmosphere can be monitored and information relayed over several hours to determine the direction of flow.

### 16.4.5 Monitoring of Environment

In the case of release of toxic materials, there are possibilities of contamination of water bodies and public water supply. This poses severe risks to all populations. Immediate and continued analysis of water for toxic materials or their derivatives is necessary. Laboratories of research institutions and universities have to be mobilized to carry out such analysis which may be difficult, especially when they are not familiar with these. False estimations of high concentrations may spread panic. Similarly soil and surfaces should be continuously examined. Monitoring should be continued for several days or weeks. Periodic checks should be done subsequently also.

### 16.4.6 Damage to Life Systems

The immediate consequences of release of toxic, corrosive or irritant materials is noticeable from the effects on man, animals and flora. While there may be damage to factory staff, they are usually well informed about the hazard and can take precautions in an appropriate manner by moving away to safe locations and by donning safety equipment. The public however are caught unaware and are totally bewildered. Panic, confusion and fear are the result. There is much anxiety about relatives and friends who are not reachable. Many tend to go out into the open streets risking further exposure. There may also be a general exodus wherein traffic snarls and blockages invariably result. In many temperate and tropical areas, many live in relatively unprotected semi-open dwellings and get exposed. Severe irritation, coughing, breathlessness, burning of eyes, throat, lungs are noted. There is a general rush to the hospitals and clinics.

If information is provided to doctors quickly, it is possible to render appropriate relief and assistance. Radio and loudspeakers in vans should be mobilized for relaying information.

In certain cases, special medical supplies are urgently required. Local medical and paramedical personnel are not able to cope with the total demand. By contacting national or regional capital and military authorities, adequate numbers of doctors and medical supplies can be brought in.

It is also necessary in some cases to requisition buildings such as schools or community centres to house those affected. Since many may be affected while away from homes, information should be provided to households to reduce anxiety and suffering.

Animals, birds and fish are also affected visibly. There may be mortalities. Special steps are necessary to remove carcasses and arrange for post-mortem examination. They provide valuable information on the nature of toxic effects and these in turn can lead to methods of treatment on affected human and animal populations. Veterinary personnel should be mobilized for such actions. Material from post-mortem should be preserved for future detailed examination with correct identification and descriptions. Similar steps are essential in cases of death of human beings either immediately or later.

### 16.4.7 Non-Gaseous Leakage of Chemicals

The accidental leakage of solids and high boiling liquids may have a lower area of spread, unless they have been released through a major explosion. In such cases, dispersion is slow. The products tend to stay on in the environment for many months and even years, if they are stable to moisture, air and light. Pesticides, agrochemicals, defoliants, herbicides, drugs, stable toxic intermediates, steroids and certain types of synthetic hormones belong to such a category. They cling to soil and surfaces. In such cases, evacuation of area and resettlement of population pose special problems as destruction of toxic material will be extremely difficult. Disposal squads themselves will need special equipment.

A particularly serious problem is the leakage of such materials into ports, harbours and rivers from boats. Decontamination may take many months involving total disruption of all normal activities.

### 16.4.8 Special Situations with Residues of Toxic Material

It is possible that after accidental leakage of toxic material clean-up is prematurely stopped. Large quantities of the same material, toxic intermediates, raw materials or finished products may remain in the unit. There is apprehension of a further release of such materials, especially if they are considered unstable or if the plants, pipelines, storage vessels containing these have also been partially damaged due to explosion. Such possibilities are very real in a multi-unit chemical factory or in a special area for storage of chemicals or in ports or railways yards. Such a situation demands very special management. A full inventory of all materials has to be prepared and the plant and systems inspected. If utilities are damaged transfers and disposals are very difficult. A high level of multi-disciplinary expertise is immediately necessary. It is also possible that staff of the chemical unit have themselves suffered seriously in the accident. It is necessary to mobilize all unaffected staff who are familiar with plant operations and supplement them with additional personnel from other chemical units. Each situation will be unique and will require the greatest care for management. Every eventuality has to be anticipated and to the extent possible, alternative sets of action have to be outlined in advance. In processing remaining materials, there are clearly very high risks of fire, explosion and further leakage. It is desirable to arrange for the surrounding area to be evacuated. Meteorological information would indicate direction of spread and rates of such spread in the event of a further accident. The situation is not unlike that of a defusing of an unexploded bomb. Depending on the nature of risks, the following steps are necessary:

1. Devise detailed procedure for safe conversion of material to stable non-toxic product.

2. Protect other equipment in the area to minimize damage by any explosion or fire. Remove all other flammable non-toxic materials in the neighbourhood.
3. Assuming possibility of further accident, sudden leakage, devise measures for containment within the plant. A second level of containment within factory or storage farm area may be detailed and facilities installed. A third level of containment just outside the boundary of the factory area is also necessary to minimize effects.
4. Public and civic authorities should be fully kept informed so that a minimum of personnel are in open areas where there are risks of exposure in the event of further leakage.
5. The team for such operations in the factory should be fully familiar with steps to be taken in the event of a further accident and should be quickly trained to act. Command and communication posts should be established for management within the unit and for contact with outside.
6. With such defined preparedness and clear appreciation of uncertainties, disposal with minimum damage would be possible.

## 16.5 CONCLUSIONS

The initial management of chemical accidents requires a thorough knowledge of properties of materials, their reactivity under varied conditions, the circumstances of the accident, estimate of nature and quantity of various products released and their effects on life systems and environment. The relief measures depend largely on such knowledge. Containment of toxic material, disposal and decontamination again demand a multi-disciplinary scientific approach. High levels of discipline and coordination are required. Further complications and risks may arise from continued presence of additional hazardous and toxic materials in the same area and in plants which are partially damaged. The management of further safe disposal requires quick scientific investigations, and formulation of multiple levels of containment to prevent further consequential damage.

In the case of stable toxic materials released into the environment, prolonged monitoring and observation are required. Each event in each location is unique and calls for approriate remedial measures.

With the growth in volume and variety of chemicals produced in thousands of units and their transportation and distribution, much greater care is required in design, engineering, fabrication, construction, operation and maintenance of plants than ever before. Open discussion and disclosure by scientists and technologists and manufacturing units are urgently needed to ensure greater safety.

General references are included in the Appendix in Part A of this volume.