CONTENTS

BACKGROUND AND EXECUTIVE SUMMARY

1. INTRODUCTION

Chemical accidents may arise in a number of ways at different stages of the life cycle of chemicals such as manufacturing, processing, storage, transportation, use and disposal. Types of chemical accidents having a potential for affecting both occupationally and non-occupationally exposed people include explosion, fire, misuse and spill. According to features of an accident, different types of hazards such as exposure to toxic chemicals, thermal radiation, flying debris and/or blast wave, may exist. If a significant environmental contamination occurs as a consequence of an accident, health hazards tend to persist long after the accident and possibly to involve also people not directly exposed at the moment of the accident. In such a case, the hazard is likely to evolve with time in view of the time-dependent and dynamic nature of contamination.

Chemical accidents may affect human health causing mortality and morbidity in exposed people. Illnesses caused by chemical accidents may be immediate or delayed. Delayed health effects caused by exposure to toxic chemicals are more difficult to be associated with the accident than acute effects. Such an association may require clinical and epidemiological surveys lasting for many years after the accident. Chemical accidents may also affect ecosystems and non-human living organisms. Often both wild and domestic animals bear the major impact of chemical accidents due to the fact that they are more directly exposed to toxic substances and are less protected in case of accidents. An indirect impact of chemical accidents on food-producing animals may derive from the prohibition of rising such animals in the affected area to prevent human poisoning through food chain contamination. In case of accidents involving the release of large amounts of highly toxic and persistent chemicals requiring evacuation of the inhabitants for preventive reasons, social and economic impacts are also likely to be very high.

Most chemical accidents have only a minor impact on human health or the environment and often are not even reported. Accidents that have more frequently caused human fatalities are those involving toxic gases, extremely toxic materials, flammable liquid or gases and unstable or highly reactive materials (HSC, 1976, 1979 and 1984). The advisory committee on major hazards of the U.K. Health and Safety Commission calculated "mortality indices", i.e. the number of fatalities per tonne of material released as a consequence of the above-mentioned types of accidents. On the basis of the analysis carried out, the UK Committee concluded that tonne-per-tonne conventional explosives, ammonium nitrate, flammable gases and chlorine, seem to have been about equally hazardous (mean mortality indices ranging from 0.1 to 0.6) with ammonia appearing to be less dangerous (mean mortality index equal to 0.02). In 1984 the most severe chemical accidents occurred in the last 40 years took place. About 350 fatalities, 5000 injured and many dispersed people resulted from explosion and fire involving butane gas containers at San Juan Ixhuatepec (2 km from Mexico City, Mexico) in November 1984 and about 2500 fatalities and 100.000 injured resulted from explosion of a methylisocyanate container at Bhopal (India) in December 1984 (Lepkowski, 1985). Accidents with no fatalities have also had major environmental impacts. This is clearly shown by the many oil spills occurred so far worldwide and by the accidents occurred at Seveso and Manfredonia in Italy in 1976 where in both cases highly toxic substances (i.e. 2,3,7,8-tetrachlorodibenzo-p-dioxin and arsenic, respectively) were involved (Pocchiari et al, 1986; Zapponi and Bianchi, 1980).

The volume and variety of chemicals being extracted, manufactured, marketed, stored, used and disposed of as waste is, on a worldwide scale, steadily increasing. This is due to the fact that many countries are characterized by a rapid growth of the agro-industry, of mining and metal production and of chemical and/or energy transformation industries as well as to the innovative character of chemical industry. This situation creates a growing likelihood for accidents involving the release of potentially toxic chemicals.
Most countries have some sort of emergencies system for natural accidents, but often these systems are not prepared for the additional requirements for information and expertise associated with an accidental release of toxic chemicals. In fact, in such a case, it is also necessary to know the toxic, physical, and chemical properties of the chemicals released, the levels of risk involved in exposure of human beings, and possible ways to deal with them.

Although in many countries chemical industry, as compared to other types of industry, has good safety records, there is a strong need for an increased awareness of potential dangers associated with chemical accidents and it is essential that chemical and related industries keep peace with prevention of accidents and when this fails, with mitigation of consequences. This is only possible with an adequate chemical accident preparedness that is not necessarily costly and in a long run pays for itself. Chemical accident preparedness (Fig. I. 1) refers to all activities documents, formal and informal agreements and social arrangements intended to reduce the probability of accidents involving the release of chemicals and the severity of the disruption caused by their occurrence (Fawcett and Wood, 1982; Silano, 1985). To be successfully and timely performed all these activities require accurate planning before the accident takes place to develop effective systems to respond to specific emergencies and to carry out rehabilitation of affected people and areas following the accident. The first key step for all the activities aiming at controlling chemical accidents is the evaluation of accident hazards imposed by installations, developments and/or operations involving potentially toxic chemicals. This evaluation should cover likelihood of accidents, possible causes, effects on human beings and the evironment and practicable control measures, including those for prevention as well as minimization of accident consequences. After a chemical accident has occurred three main phases of activity follow which are conceptually distinct although much less so in reality: (i) the emergency phase which may be concluded in a relatively short time; (ii) the follow up phase, which is the real substance of emergency response activities and may continue for days; and (iii) the rehabilitation phase, which may take weeks, months and even years to accomplish (Fig. I.1).

The World Health Organization has long recognized the health aspects of chemicals. Following the resolution adopted at the twentyninth session of the Regional Committee in Helsinki in September 1979, the European Regional Office launched an intensive programme on toxic chemicals control. A major component of this programme is related to accidents involving the release of potentially toxic chemicals. Future plans of WHO/EURO are focussed on evaluation and prevention of accident hazards, whereas past activity dealt with producing guidelines to assist countries in developing strategies for preparing effective contingency planning systems to respond to specific emergencies (WHO/EURO, 1981).

The present document consists of a comprehensive set of executive guidelines to assist Member Countries in developing strategies for assessing rehabilitation needs and implementing rehabilitation actions of affected human beings and damaged ecological systems following major chemical accidents; it is intended to provide guidance to governments at all levels in managing the remedial activities in an effective and rational manner. In this context, major chemical accidents indicate unanticipated, episodic and relatively rare events, frequently originating from a point sources and potentially damaging by causing adverse effects on a large number of people and/or the environment outside the immediate site of release of the chemical(s). Rehabilitation of human beings implies the return, to fullest extent possible, to the pre-accident health state through post-emergency health care. Damage to people will be first a medical assignment but social rehabilitation should follow and not be left to nature to heal. Rehabilitation of environmental components (e.g. soil, water, buildings and facilities) means full recovery, partial recovey or alterations. A wide range of possible remedial actions may be used to reduce the hazard coming from a site where chemicals have been discharged. The actions may range from doing nothing to elaborate restoration of the original site including removal of all traces of the hazardous chemicals and replacement of soil, vegetation and buildings that may have been contaminated. Ecological rehabilitations are likely to result in a certain amount of alteration if only because natural vegetation may take centuries to stabilize. An ecological rehabilitation programme is thus a specific assignment to be defined in terms of various goals which can be evaluated in terms of costs and results. The physical aspects of a rehabilitation programme are an engineering assignment.

Health effects and environmental effects of major chemical accidents are not easily separable, especially if an accident has long-term environmental effects which present recurring health hazards. In an accident with impacts on human health, it is obvious that these impacts will be the primary focus of attention for all concerned. The environment is seen mainly as a carrier of toxicity to the affected populations, and its characteristics are of concern for the purposes of diagnosis of possible hazards. In accidents that involve no immediate health risk, but which create severe damage to a physical area, the "health" of the ecosystem affected becomes of concern. However, in many accidents, such as long-term or very sizeable chemical accidents, both human health and environmental quality considerations become important. In these cases it is important to work out ways of integrating the management of both human and environmental rehabilitation. As a result, in this document no attempt has been made to define rehabilitation goals applicable under all circumstances.

A Workshop on "Rehabilitation following Chemical Accidents" jointly organized by WHO/EURO and the Istituto Superiore di Sanità, was held in Rome, 8-12 November 1982. The present document is a result of that workshop which called for a guideline document on rehabilitation after major chemical accidents. It is made up of several independently prepared documents dealing with various aspects of rehabilitation (see list in Annex I). The separate works have been edited to reduce redundancy and to remove material that seemed beyond the scope of the assignment. The editors have also filled in some gaps, have reworded a few sections and have rearranged others so that individual authorship may not be recognizeable.

2. ESTABLISHMENT OF A REHABILITATION TASK FORCE

The establishment of a rehabilitation task force is normally the first and key step of the rehabilitation process. The very nature of the duties of rehabilitation task force is likely to change with time. At the beginning the main duty is likely to be the assessment of rehabilitation needs and the development of an action plan. As the work proceeds, main duties become the performance of the different components of the rehabilitation programme, monitoring and adjustment of the programme, and information and experience transfer. As the main emphasis of the rehabilitation work changes, the membership of a rehabilitation task force should be adjusted accordingly, but continuity should be ensured particularly at a decision making level. The transition between emergency response and planned rehabilitation is best mediated by a representative group from the initial respondents and the future overseer. The optimum solution for the establishment of a rehabilitation task force should emerge from consideration of rehabilitation options. All the experts of the various disciplines involved should form a scientific executive body and be aware of each other's plans to avoid conflict and maintain smooth execution. Two types of personnel are essential for a task force: those who can properly interpret the situation and those who can properly execute the actions that the interpretation and assessment imply. The rehabilitation task force should aim at helping local services to re-establish full responsibility for routine diagnosis and treatment. If not available at local level, special financial and technical help should be provided. No parallel health or environmental systems should be developped, unless absolutely necessary. External Agencies and Organizations can help by providing support for training activities and specific methodologies, by performing special trials and studies and carrying out activities that cannot be carried out at a local level. Collaboration of the rehabilitation task force with local services is essential; it can be more effectively ensured if representatives of the local services are members of the task force. The task force should also include representives of the Bodies (e.g. central or regional Governments) providing financial support to rehabilitation programmes.

3. ASSESSMENT OF REHABILITATION NEEDS

Available information must be gathered on all the aspects listed in Table 1 and screened by the task force in order to diagnose the situation and develop an action plan.

For the manager faced with a sudden deluge of information, often incompatible, even irrelevant, the ultimate criterion is the uses to which the information can be put. This implies a coherent framework for interpretation. The sequence is: Data-Interpretation-Diagnosis-Planning-Implementation, but at each stage there are feedback loops that modify data-gathering, types of interpretation, etc.

Determination of the source of an accident, whether self-evident or not, whether a point source or diffused, is perhaps the single most important piece of information required after discovery of the accident. This is obviously the case because the accident may be continuing, and the most important information concerning the severity of an accident is only obtainable at the source. There are distinct differences between accidents such as explosions or transportation accidents with easily identifiable point sources, and accidents occurring at an unidentified location point and having an unknown contaminant (e.g. food supply). The former is usually much easier to contain and manage than the latter. Similarly for non-point sources, identified sources are more easily managed than unidentified sources. There are several possible combinations of known and unknown sources, known and unknown chemicals, and point and non-point sources as shown in Figure 2. It should be noted that different management schemes and concerns derive from each combination. The most difficult combination to manage is II-2-B, an unknown non-point source of an un-known chemical; the easiest I-1-A, a known point source of a known chemical. An example of the former might be an abandoned hazardous dump site where neither the location nor the chemicals involved are known. An example of the latter might be the derailment of a placarded train carrying a particular chemical. Variants between these extremes encompass the range of possible accidents.

Rarely will a manager of a rehabilitation project be presented with a complete and clear set of information. Beyond the available standard information at his command, the emergency response will have identified the boundaries of the area for future analysis. As a result, there is probably substantial evidence available requiring careful interpretation. The manager's job is to assess the quality of this information, to reveal gaps, and to consider if the initial interpretations drawn are correct. This first step becomes a prototype for subsequent analyses during the course of rehabilitation. Each accident is unique, and standardized plans must be flexible enough to take this into account. A systems model, drawn from planning theory, may be of assistance in clarifying the process being advocated (Figure 3). In the planning process, emphasis begins with the site analysis, and then turns to site development; in the rehabilitation process, emphasis also begins with the survey of what is happening (or has happened) at a particular site, and then proceeds to the implementation of whatever rehabilitation model has been decided upon.

The manager should utilize available data to make an initial reconnaissance and try to connect them with the anecdotal information obtained from site workers and emergency personnel and such technical surveys as have been carried out, initially to delineate the area and level of concern. It should in no sense cut off speculation, nor should it be final. A two-tiered approach may therefore be essential: encouraging speculation and yet presenting a measure of confidence to the public. Confidence in the responsible officials is usually crucial for success so this two-tier system must be managed very carefully; and may not be as effective as admitting the bounds of uncertainty at the outset.

Human health impacts are usually of greatest concern, so the most important interpretative effort for a manager is to relate the potential toxicity with the observed toxic effects of the chemical(s). Observed effects are of great importance during the earliest phase of an accident. It is relatively easy to interpret very localized large-scale damage from a substantial and recently released chemical. Certainty is probably inversely related to time and distance from an accident. As chemicals are exposed to various environmental conditions and move through various routes or pathways, impacts become difficult to model, anticipate, or diagnose. Speed is therefore of the essence.

4. DEVELOPMENT OF AN ACTION PLAN

Having diagnosed the damage caused by the accident, the next step is to decide some form of rehabilitation. The needs for rehabilitation will have to be assessed, priorities fixed and rehabilitation schedules prepared considering all alternatives. The assessment of rehabilitation needs must consider the health and social care of the human victims, domestic animals as well as the restoration or repair of the accident site bearing in mind the constraints imposed by time and resources.

The basic components of an action plan for rehabilitation are:
a) Post-emergency health care
b) Post-emergency social care
c) Post-emergecy economic aid
d) Recovery of ecological balance
The status that existed before the accident is an obvious standard of reference and for all practical purposes the return to that status is likely to fulfill the objectives of the rehabilitation programme. Rehabilitation is an iterative process. Resources are normally made available gradually as the remedial action has shown itself to be effective. This calls for a very flexible rehabilitation plan. It is clear that eventually the rehabilitation plan designed has to be fitted into a framework where both time and resources are unavoidable constraints. Planning for action must therefore include alternatives. Moreover, it is essential that the selection and implementation of a rehabilitation be accompanied by a monitoring or feedback stage, where tha results of the rehabilitation scheme are themselves assessed.

A key factor in developping an action plan is time. What is a reasonable length of time to complete the process of rehabilitation? Is a community prepared to live with the consequences of an oil spill while nature takes its course? Will this delay be acceptable to the people concerned? Rehabilitation may require an overlapping series of timetables which may complicate the planning process. An interim measure unrelated to the goals of rehabilitation may necessitate a change of strategy revising completely the timetable. The public of today is very sensitive to issues of environmental concern and may demands rapid solution to problems.

5. REHABILITATION OF PEOPLE

Rehabilitation of people includes several components, i.e. post emergency medical, social, economic and psychological cares and health surveillance system.

5.1 Post emergency medical care

Medical rehabilitation follow from emergency care to whatever extent of recovery is possible. In most chemical accidents, treatment of the victims is likely to be not different from normal treatment for sick patients showing similar symptoms and diseases. If specialized clinical help is needed, it should be provided ensuring strict collaboration with local health services. For some poisons, appropriate antidotes and treatments may exist; they should be available to the victims of the accident. Ignorance of the toxic substance(s) released may hamper the secondary care as well as the emergency care.

After the emergency phase is over, the treatment covers several areas, e.g.

- Treatment according to symptoms of the pathology initiated by the toxic substance. According to severity and evolution of the pathology, this treatment can be of short or long duration.

- Discussion on pregnancy in cases of high foetal malformation risk.

The treatment following the emergency phase should still be a responsibility of the medical staff normally peforming on the site of the accident, in order to avoid undue anxiety among the population. The diagnosis and treatment should ideally be performed by specialists in the different relevant health effects. If external specialized clinical help to local hospitals is needed, it should be provided ensuring strict collaboration with the local health service. The support of anti-poisons centres and toxicological laboratories may also be necessary. In some cases, animal experiments may have to be carried out to evaluate delayed and/or chronic responses to the chemical, the mode of action, biotransformation and disposal. Sometimes in vitro tests may also give useful information.

5.2 Post emergency social, economic and psychological care

Although many of the most important aspects of social care must be carried out on an individual basis, there are a number of problems that should be attacked for the community as a whole. Financial aid to persons whose source of income has been destroyed should be prompt and as close to the direct losses as possible. Facilities for meetings and places for social activity are very important. Special attention must also be given to providing adequate information including as far as possible individual answers to questions.

The aged, sick, mentally disturbed or retarded all need special consideration in periods of crisis. Afterwards, they may need further special care to minimize the effects of the disruption of their lives. There may be a requirement for psychiatric and social counselling. The psychlogical well-being of the community may be impaired if the cause of the contamination is not clearly defined and located quickly. Uncertainty as to the possible recurrence of the accident necessarily slows down the healing process. This is especially true if the accident was believed to be caused by a local firm, since recriminations can continue for many years, rooted in rumour. The psychlogical and emotional well-being of the population are an integral part of health. Rehabilitation procedures should recognize this and provide suitable arrangements.

5.3 Health surveillance system

A surveillance system should be established as soon as possible after the accident. The surveillance system has the main purpose of evaluating:

a) the long term health impact of accident;
b) the effectiveness of post emergency medical cares;
c) the possible persistence of a threath to health depending on the environmental contamination caused by the accident, if any.

The most important interpretative effort is to relate the toxicity of the released chemicals with the health effects observed in connexion with the accident and to establish whether there is evidence of a continuing health impact of the accident.

There are three key aspects in planning any surveillance system, i.e. the exposed population, the health-related data and the organization features.

5.3.1 Exposed population

The exposed people should be registered as early as possible after the accident and before they become infiltrated by people who are simply seeking compensation. An ad hoc census is particularly important in area-wide chemical accidents; the information collected should be kept to a minimum and aimed at specific purposes. The identification of the exposed people and of the extent of exposure may be a very difficult task. There are a number of possible approaches to achieve such a task and their values depend on the characteristics of the accidents. For instance, for the accidents involving the release of a toxic chemical(s) over a wide-area, an approach might consist in defining first the affected area and then in identifying the people who were in that area at the time of the accident (and later on in the case an important environmental contamination resulted from the accident). If an assay of the released chemical(s) in human specimens (e.g. blood, urine or hair) is possible, an ad hoc biological monitoring programme is likely to provide the best definition of exposed people and extent of exposure, provided the toxicokinetic of the released chemical(s) and the exposure route are known. Lastly, if the released substance(s) is known to induce specific health effects, physiological alterations and/or symptoms, a careful screening for the specific health-related parameters may prove to be very effective for a qualitative identification of the exposed population. However, one should be very careful when asking people about symptoms as answers are likely to be biased.

5.3.2 Health-related data

Health data which should be gathered in the framework of the surveillance programme include: a) the health effects detected by the emergency and post emergency health teams; b) those related to effects observed in laboratory toxicity tests with the released chemical(s); and c) any other effects which may be suspected for specific reasons (e.g. observations carried out in previous similar accidents).

A key aspect to be defined is the balance between intensive monitoring follow up and routine health information surveillance. This decision depends on the number of presumably exposed individuals, presence of clinically detectable pathologies or subclinical objective symptoms and signs, and on the available toxicity data concerning the released chemical(s). An intensive long-term comprehensive clinical monitoring is recommended for relatively small groups showing signs of intoxication, for pregnant women and for highly toxic chemicals. When a large population is involved, the "routine" surveillance could complement the intensive surveillance on selected groups of people. Programmes with a strong clinical emphasis should be decided on the basis of a cost-benefit analysis.

Taking blood and/or urine specimens and submitting them to extensive chemico-clinical analyses may provide additional useful information if applied to well defined population groups. If this type of work is undertaken, a comprehensive quality control programme should be established and samples should be stored in order to be able to re-analyse every sample, if necessary.

According to the magnitude of the accident, the kind of hazardous agent action and the state of information on the biological effects of exposure, the need to undertake epidemiological cohort studies may arise. The procedure for such a study should be in agreement with the generally-accepted scheme. The temptation must be resisted to give too much importance to grandiose computer programmes. Adequate importance should be given not only to the collection and quality control of epidemiological data, but also to their statistical analysis.

5.3.3 Organizational aspects

A health information system capable of providing the needed health data on a routine basis should be established as soon as possible. The main information source are likely to be the hospital discharge data and mortality data. If not already in operation, a hospital activity analysis, with individual forms completed for each in-patient, should be introduced in all hospitals of the affected area. Such forms should be completed also for people resident in the affected area which are admitted to hospital located outside the area.

Morbility, malformation and cancer registries may also be created depending on the outcome(s) suspected. Input data for registries should also possibly come from normal health services. It is necessary to stimulate completeness and accuracy of reporting.

The duration of the surveillance programme depends on the specific accidents considered. If acute health effects are observed, the surveillance programme should not end before the therapy has achieved best achievable results. If chronic effects are suspected, the surveillance should last enough time to prove or exclude the occurrence of such effects; in practical terms, this may mean a 30-years or more surveillance project. If no health effects are detected and no chronic effects are suspected, surveillance can be discontinued after several months.

6. ECOLOGICAL DAMAGE RECOVERY

Following accidental release into the general environment of toxic chemicals and depending on the environmental compartment affected, a range of possible methods exists for containing, cleaning and removing unwanted materials. They include (Smith, 1985) those that remove contaminants or render them harmless and those that prevent or decrease the further release of contaminants.

All these actions require a multi-disciplinary approaches. If the first group of actions are carried out properly, they provide an ultimate solution and the question of long-term effectiveness does not arise. All other technologies offer a solution of only limited or uncertain
duration unless other mechanisms, such as microbial attack, are such as to reduce the level of contamination. They need maintenance and renewal as long as the contaminants inside are present and their release would be considered harmful. Despite a potentially limited lifetime such measures may prevent or reduce the release of contaminants for as long as is considered necessary or may provide time in which longer-term solutions can be developed.

Available remedial actions can be grouped as follows (Smith, 1985):

a) on-site processing of contaminated materials
b) in-situ treatment of contamination
c) covering and capping the contaminated land
d) in-ground macroencapsulation (barrier system)
e) hydraulic measures

On-site processing of contaminated materials include methods of decontaminating by: excavation; treatment to detoxify, neutralise, stabilise or fixate; and usually redeposition on-site. In-situ treatment of contamination includes methods of treating, without excavation, the bulk material on a contaminated site by detoxifying, neutralising, degrading, immobilising or otherwise rendering harmless contaminants where they are found. Cover systems for contaminated sites include systems designed to prevent the migration of contaminants vetically upwards or to prevent ingress of surface water into contaminated sites. In-ground macroencapsulation includes systems designed to prevent migration of contaminants vertically or laterally, or to prevent ingress of ground water into contaminated sites. Hydraulic measures are operations designed to control or treat the liquid phase on contaminated sites, i.e. groundwater modification systems and in-situ or off-site treatment of contaminated groundwater. Choice of the most appropriate method for dealing with contaminants in order to rehabilitate land depends on a wide variety of features such as those indicated in Table 2.

6.1 Rehabilitation of water

The actions necessary to achieve the rehabilitation of a contaminated water resource divide into two phases. Firstly there are those actions designed to arrest the spread of contaminated water from the site of the spill and secondly there is the application of appropriate technologies to remove, or at least permanently reduce the contamination within the water body so that it may be returned to an acceptable use. In many cases spillages will occur on the land surface, not directly into a body of water. The first action to be taken must be to stop the continuation of discharge whenever possible.

In areas of low permeability soils, spilled liquids are likely to flow towards drainage channels and the next step is therefore to impound the flow by construction of a barrier (bunding). On ground level a bund should be built encircling the spill area, whilst on sloping surfaces a wall constructed across the flow path, with a convex shape in the downhill direction, will collect and stop the flow of liquid. In some cases the same effect may be achieved by rapid excavation of a pit across the flow path of the spill. Liquids collected in bunded areas or in excavation should be removed by pumping to secure, intact containers as soon as possible, taking account of any necessary safety precautions.

After the initial isolation of the polluted water, several actions may be taken to improve its quality to the point where it meets quality standards appropriate to direct use, discharge to surface waters, reinjection to an aquifer or some other specified use. The options may be classified into two main groups:

a) In-situ enhancement of natural processes and attenuating mechanisms present in the environment (e.g. neutralisation, oxydation and aerobic biological degradation);
b) Application of physical (e.g. gravity separation, skimming, filtration), chemical (e.g. activated carbon adsorption, ion-exchange, neutralisation, chemical precipitation, reduction or oxidation) and biological treatment methods to water which has been removed or isolated from its immediate surrounding, either at the site of the accident, or elsewhere, possibly a municipal waste treatment plant.

6.2 Rehabilitation of soil

Physical removal and disposal of contaminated soil in a safe site constitutes the best known and most widely practised method for rehabilitation after chemical spills on land. Standard excavation techniques such as manual and mechanical shovelling and scrapers may be used. Excavation and removal of the contaminated material for deposition elesewhere is not always an acceptable or practicable option. There can be major environmental impacts whilst the work is in progress and the problem may be simply transferred elsewhere to re-emerge later. Nor is excavation a simple process or one that can be carried out without recourse to other remedial operations such as creation of barrier walls and treatment of groundwater. The major disadvantages for this approach are:

(i) difficulties of disposal site selection;
(ii) removal of large volumes of soil is very expensive;
(iii) special equipment may be required for excavation, for transportation, and for personnel involved;
(iv) transit liabilities;
(v) requirement for restoration and landscaping.

If soil removal is not appropriate, there are several methods for treating soil including physical, physico-chemical, chemical, and biological ones (Table 3). These are based on the physical and chemical properties of the material spilt and a range of parameters that define the detail of the site where the spill occurred.

Physical methods are well developed:

a) Surface sealing consists in spreading an impermeable surface layer of plastic or an inert material, e.g. PVC, clay or concrete. However, it is necessary to protect the surface layer from external deterioration by applying a sand layer on top. Long-term stability is difficult to assess.
b) Laterial isolation prevents the transport of contaminated water out of the area. This is accomplished by steel sheeting or by use of an inert material such as granite or asphalt. The barriers may corrode or may not always be impermeable. Pumping may be required to remove contaminated water.
c) Flooding is useful where the water table is high. The most common method is to pump water into the soil through wells in order to raise the water level and then to collect the surface run-off.
d) Steaming or heating can be used to vapourize the contaminant which leaves the soil and enteres the air. Assessment of the pattern of dispersion and the acceptability of the consequent concentration is necessary. Monitoring of this procedure is most important.

Physico-chemical methods offer several means leading to rehabilitation:

a) Dispersants have been used mainly on surface contamination. Their action is to break up the material, e.g. oil, whereby it can then be entrained in a washing medium, e.g. water. Dispersion of contaminants in land presents problems of both access and control.
b) Sorbents vary in nature, but they have the ability to accommodate quantities of contaminant that is then removed with the sorbent.
c) Complete containment, which is also known as encapsulation, involves surface, lateral and bottom sealing and, in essence, the chemical spill area becomes a permanent disposal site and its reuse is unlikely. Several different types of sealants may be used such as clay, asphalt and organic based compounds. Bottom sealing is the most difficult process and therefore the sealing is usually pumped.
d) Gelling agents can be used to render a liquid less mobile, thereby delaying the spread and simplifying the problem of collection (perhaps by mechanical means). Gelling is ideally suited to prevent flow to surface water, and minimize percolation into soil. Spilt chemicals that polymerize could also be cleaned up by this method.
e) Foaming agents, such as protein, fluoroprotein, alcohol and film forming materials, may be used to achieve separation by froth flotation and to prevent evaporation and gas phase spread.
f) Solvents have also been suggested. Only a few pollutants can be successfully removed from soil by extraction. Their use would necessitate closely controlled conditions. The appropriate solvent would have to be easily removed and small quantities of it not deleterious to the environment.

Chemical methods include:

a) Neutralization can be applied to spills of either acids or bases. Among common neutralizing agents are sodium bicarbonate for acids and sodium dihydrogen phosphate for bases.
b) Precipitation may be employed to immobilize the contaminant. The treatment of soluble heavy metals is possible with this method. After immobilization, it is likely that soil removal, followed by grading and landscaping, will be necessary in order to rehabilitate the site.
c) Complexing agents wherein liquids that are usually organic in nature bond with metals, offers another means of immobilizing soluble metal ions. Ethylenediaminetetracetic acid (EDTA) is a typical agent of this type for complexing metals such as iron, nickel, lead, copper and mercury.
d) Leaching is an extraction process whereby a solvent is used to extract a substance; the process often involves chemical reactions. Sulphuric acid is an example of a leaching agent that reacts with metals and enables them to be removed.
e) Incineration may be used to burn a material in situ, particularly under conditions where pools or puddles form as from spillage of a flammable solvent. If such a material has soaked into the soil, the site may be excavated and the contaminated soil incinerated; the residue may then be landfilled. Such methods call for careful assessment of the air pollution problem that may be caused by the products of combustion of the contaminant.

Biological methods:

a) Biological treatments involve the use of microorganisms to either remove or degrade a spill of chemical material. As with activated sludge, land spreading and similar methods to domestic waste treatment may be used.
b) On site treatments involve the excavation of soil and subsequent washing in either mobile or temporary plant facilities. Several techniques are possible, such as reverse osmosis to reduce concentration. Incineration is possible on site with a portable rotary kiln.
c) Natural degradation. In some cases, the alternative methods may adversely affect the enrivonment or may be too costly and hence the best method would be to let the land lie fallow or to plough it in order to facilitate evaporation of the chemical(s). Vegetation may also help removal of contaminant from the soil.

6.3 Rehabilitation of buildings

Buildings may be affected in several ways by chemical accidents. They may receive liquid by direct impingement and brick, walls, plaster and woodwork may be impregnated. If the material is corrosive and/or toxic, removal of the affected parts will be necessary. If, however, the contaminant is a gas or vapour, rehabilitation of the original building may be possible. Solids are unlikely to have more than a local and readily removed effect on the building.

There are a number of ways which can be considered for rehabilitation of buildings. They are:

a) Washing with water or other solvents to either wash away or dissolve the contaminants; the resulting effluent would have to be collected and either treated or disposed of.
b) Sealing, if no other alternative is possible; the building may have to be sealed completely to prevent any contaminated material from being released.
c) Steaming could be applied to walls and floors to vapourize the contaminated material; safe disposal or dispersion of the vapour must be arranged.
d) Scorching of surfaces, i.e. burning of the material. In both this case and the previous one, protection of operators is necessary as well as the prevention of release of the contaminated material to the environment.
e) Ventilation by large fans may be used but this involves the cleaning of exhaust; protection of operators is necessary as well as release of the contaminated material to the environment.
f) Air or sand blasting - use of high pressure air or sand to clear away the outer surface of a building.
g) Photolysis - this method works rather well only for susceptible compounds when the favorable conditions are created.
h) Coating of surfaces with paint or synthetic varnish to absorb or immobilize the contaminants.
i) Destruction may be necessary, i.e. to demolish the building and to carefully transport it to a site where contaminants of the type involved may be disposed safely, e.g. by incineration, treatment with chemical reagents.

6.4 Rehabilitation of facilities

Facilities include contents of buildings, transportation vehicles, and plant and equipment.

Contents of buildings. Contents of buildings such as furniture can be washed, chemically treated *in situ* or at a treatment facility, or destroyed. The simplest and cheapest alternative may be the last one.

Transportation vehicles. This includes cars, buses, trucks, and tank cars. They also may be washed, body and trim repaired or stripped and treated separately. Destruction under controlled conditions may be the best alternative.

Plant and equipment may be dealt with by similar treatment to the contents of buildings.

Storage. Contamination of storage or warehouse areas may present several hazards and difficulties in rehabilitation. Contamination of other chemicals may create flammable or toxic compounds and limit the possible solutions.

6.5 Hazards and precautions

Very few methods of rehabilitation are free from hazards; secondary damage can readily be done while removing the effects of the primary agent. Hazards of rehabilitation have to be considered as they may impact on:

- rehabilitation workers;
- residents and employees in the area and its environment;
- environment and personnel in places to which contaminated material is moved.

Toxic and flammable hazards are two of the more obvious matters. Effects on the total environment wherein disturbances of the food chain may produce widespread detrimental results must be avoided.
The rehabilitation workers may be undertaking unfamiliar tasks and even familiar jobs in unusual circumstances. Such situation are likely to produce accidents. Training and informed supervision will minimize such accidents. Wherever rehabilitation work is undertaken, it is essential to analyze the possible effects of the proposed actions prior to commencement of the work. Unwanted side-effects not only have to be considered but monitored from the inception of the clean-up. Local residents should be informed and may have to be evacuated. In some cases, hospital checks will be necessary. Protection of rehabilitation workers may be a major task. The use of protective equipment, e.g. boots, gloves, impervious coveralls, masks, self-contained breathing apparatus, may be necessary over long periods.

Transportation of contaminated soil and of the remains of demolished buildings has to be undertaken safely. Such materials must be carried in high integrity containment. this and all clean-up equipment must be able to withstand the rigours of the particular situatione.g. corrosivity.

6.6 Environmental monitoring

Information obtained by repeated analytical monitoring of the affected areas is essential to evaluate how contamination evolves with time. At the end of an emergency, an accurate picture of environmental contamination will help in deciding on the most appropriate measures to be taken for rehabilitation. Moreover, evaluating the public and environmental impacts of an accident, as well as the consequence of changes with time within the affected area by a long-term monitoring programme, is essential for effective handling of the post-emergency phase, and for determination of the effectiveness of rehabilitation.
Measuring and monitoring of environmental behaviour of chemical(s) should be a nearly continuous activity based on several essential features such as experimental design, sampling plan, sequential flexible procedure, evaluation of measurement errors, quality control procedures and hypothesis testing.

Environmental compartments that would require monitoring in case of an accidental release of toxic chemicals depend on the dynamic of the accident. Soil, sediments, water, and vegetation are most likely to be included in the after-accident monitoring programme.
Surveillance of soil and vegetation would be particularly important

where accidents have affected above or near-surface environments. Monitoring programmes would generally consider:

- the distribution of contaminants in soil;
- the availability of contaminants in soils to vegetation;
- the effect of contaminant uptake on plants;
- long term adjustement of flora in response to contamination and its recession.

Waters within a contaminated area which would need to be considered include those indicated in Table 4. Planning for monitoring of water resources and their possible rehabilitation requires a thorough knowledge of the dynamics of the surface/groundwater/pollutant systems, which may only be obtained by extensive field investigations and laboratory studies. Collection, collation and interpretation of data relating to groundwater pollution should start as soon as possible after the accident. Suitable sampling points for both groundwater and surface water may exist in the affected area, but frequently it will be necessary to drill boreholes to provide additional groundwater/soil pore water sampling and monitoring points within the prescribed areas.

Monitoring of areas within a contaminated area may be done to measure the spread of pollution, e.g. earthworms or birds at the top of food chains. Autopsies of dead or obviously diseased animals may be useful especially if combined which chemical analyses for pollutants. Fish and other aquatic animals are useful indicators of water pollution.
Monitoring of locally produced food and animal feed would normally be required to protect human and animal populations from exposure to contaminants via their respective food chains. In the long-term, it would also be necessary to continue this surveillance, to monitor possible clean-up of the contaminated area, and to assess the advisability of recommencement of agricultural and/or horticultural activities in the affected area which may have been curtailed following an accidental release. Where locally-produced crops, food and feed are consumed by the resident human and animal populations, monitoring of crops will be required to continue to protect the consumer, and to provide a record and diet and levels of contaminant ingestion, e.g. for use in epidemiological studies.

The extent of chemical contamination of internal building surfaces and facilities can be established by means of wipe tests conducted on samples taken from internal and external walls, floors, and windows as well as from metal parts. An appropriate area is chosen for each sampling and then subjected to horizontal and vertical wiping with a cotton swab imbibed with an idoneous solvent; then swabs are put in suitable jars to be further used for extraction and assay of the chemical contaminant(s).

7. FEEDBACK AND ADJUSTMENT

A systematic feedback and adjustement process must be ensured. The assessment of effectiveness of rehabilitation of people and environmental systems is based on re-evaluation of fact as they evolve in time and in space. This assessment implies a continuous decision making process capable of synthesizing the past events and using new information to continuously develop strategies for the future as the programme evolves. Any new decision taken during rehabilitation requires some modifications of the work carried out by the rehabilitation teams. This implies a precise role of the responsible team.

Continuity of responsibilities should be maintained throughout the entire rehabilitation programme. Any change in plan resulting from experience should be the responsibility of a single decision-making authority. Moreover, a provisional budget can never be really accurate for the entire rehabilitation programme, and additional budgets may be necessary as the work proceeds. The re-assessment of the plan in the light of data acquired will be easier if the objectives were clearly defined and pursued. Effectiveness is therefore dependent upon the quality of the work carried out to date. One of the difficulties of the feedback process is to ensure rigorous methodology complying strictly with the fixed objectives, yet allowing for unexpected or underestimated facts. In addition to new facts, re-examination of goals and objectives may be imposed from the new information deriving from updating literature and new results. This re-examination may lead to a re-definition of priorities and/or to an adjustement of rehabilitation plan.

The gradual halting of the programme is justified as the study protocols are terminated. The decision to stop the programme requires a clear reason justified by objective criteria.

8. INFORMATION AND EXPERIENCE TRANSFER

Accurate recording of data is very important to the purpose of programme-management and experience transfer. Data relative to methods, procedures, number and characteristics of personnel involved, resources, performances, time and costs, need to be recorded. In particular, it is necessary to report in detail the knowledge developed. It may also be important to report the critical analysis of difficulties encountered and of procedures eventually abandoned because they were impracticable or unreliable. This information is needed for a number of different purposes including legislation and standard setting, formal enquiry, public participation and manpower development and training.
The internal documentation service of an organization dealing with the rehabilitation of chemical accidents consequences should be able to provide immediately all the monitoring data (public health, soil, air, water, biota...) for the appropriate time period, population subset, environmental substratum and so on.

Other means to transfer information and experience, e.g. publications, special reports, mass media, manual and training aids and provision of experts, should be very carefully considered and exploited.

9. INTERNATIONAL CO-OPERATION

International networks are essential to provide for co-operation and will almost always be called upon to play an essential role in rehabilitation following major accidents, and complex and unique accidents, accidents close to a border, and multinational operations.

Perhaps the most important characteristics of a well-managed technical response are speed, and the appropriateness of personnel and equipment dispatched. For implementing technical assistance programmes, there is a need for the establishment of communications trough computer linked information services, network of emergency respondents or co-operative central command posts.

A highly used form of international co-operation is training of both emergency and rehabilitation personnel. These training programmes or workshops could be under both bilateral exchange programmes or under the aegis of international Agencies.

Management of rehabilitation programmes involves the transfer of technology and as such should be appropriately adapted when transferred from one country to another one.

10. CONCLUSION

The actions needed to understand and minimize long-term health and environmental effects of major chemical accidents are highly complex and require proper timing. Moreover, they require a carefull appraisal of the situation and a considerable skilfulness in planning and organizing. Excessive delays may results in the impossibility of coping with long term effects of the accident, although retrospective studies may still be possible to learn what happened.

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TABLE 1

Categories of information desirable to assess rehabilitation needs following major accidents involving the release of toxic chemicals

1. Attributes of the accident.
   1.1 Source
   1.2 Apparent cause
   1.3 Apparent reason
   1.4 Site of accident and area affected
   1.5 Amount of chemical(s) released
   1.6 Properties of chemical(s) released
   1.7 Dynamics of chemical(s) release
   1.8 Toxicity of chemical(s) released
   1.9 Main routes of exposure
   1.10 Level of resources required of rehabilitation

2. Emergency action taken

3. Observed effects
   3.1 Physical indicators
   3.2 Effects on human beings
   3.3 Effects on plants
   3.4 Effects on animals
   3.5 Social and economic effects

4. Results of initial monitoring
   4.1 Sampling
   4.2 Biological monitoring
   4.3 Physical chemical detection

5. Toxic properties of chemical(s) involved
   5.1 Human toxicity
   5.2 Ecotoxicity

6. Environmental transport and fate
   6.1 Air
   6.2 Water
   6.3 Environmental fate analysis
   6.5 Computing, modelling and evaluating

7. Properties of areas involved
   7.1 Natural systems (geography/ecology)
   7.2 Managed or built systems (physical/technical)
   7.3 Socio-economic systems

TABLE 2

Some features influencing strategies for land rehabilitation

- type of material released
- quantity released
- physical and chemical properties of the contaminant
- climate and weather conditions prevailing at the time and folloging the accident
- extent and topography of the area affected
- soil type and drainage system
- size and location of natural water courses
- proximity to and type of built-up environment
- accessibility for appropriate rehabilitation equipment

TABLE 3

Methods for rehabilitation of soil

Physical methods

a) Surface sealing
b) Lateral isolation
c) Flooding
d) Steaming or heating

Physico-chemical methods

a) Dispersants
b) Sorbents
c) Complete containment
d) Gelling agents
e) Foaming agents
f) Solvents

Chemical methods

a) Neutralization
b) Precipitation
c) Complexing agents
d) Leaching
e) Incineration

Biological methods

a) Biological treatments
b) On site treatments
c) Natural degradation

TABLE 4

Waters that would require monitoring during rehabilitation

- Precipitation (rain and snowfall)
- Surface waters (streams, rivers, lakes, reservoirs, oper drainage channels) subsurface drainage networks discharging into surface waters
- Soil water and pore water in the unsaturated zone
- Groundwater at different depths within the saturated zone beneath the regional water table, and in perched layers of saturation above the regional water table
- Water supply, distribution and wastewater disposal systems

FIG. 1— COMPONENTS OF CHEMICAL EMERGENCY PREPAREDNESS

	PHASE	ACTIVITY
BEFORE THE ACCIDENT	1) Hazards Evaluation	• Identification of hazards • Identification of vulnerabilities • Assessment of risk
	2) Prevention	• Removal of the hazard • Selection of alternatives • Hazards control
	3) Planning mitigation	• Contingency planning • Knowledge of rehabilitation methods • Instituting organizational frameworks
AFTHER THE ACCIDENT	4) Emergency	• Accurate response • Speed of action
	5) Follow—up	• Knowledge of chemical (s) • Fencing-in of the accident
	6) Rehabilitation	• Diagnosis of needs • Implementation • Monitoring • Feedback and Adjustment • Information transfer and storage

From Silano (1985)

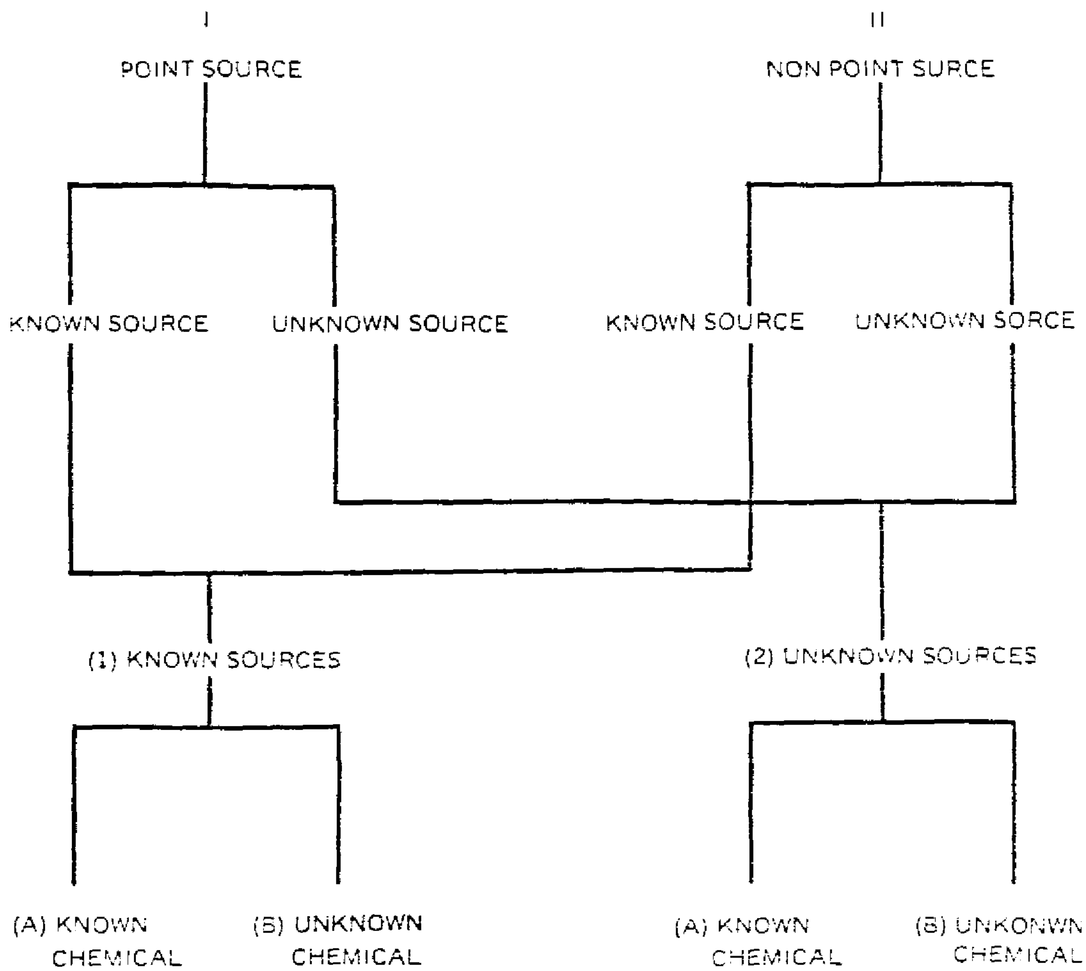
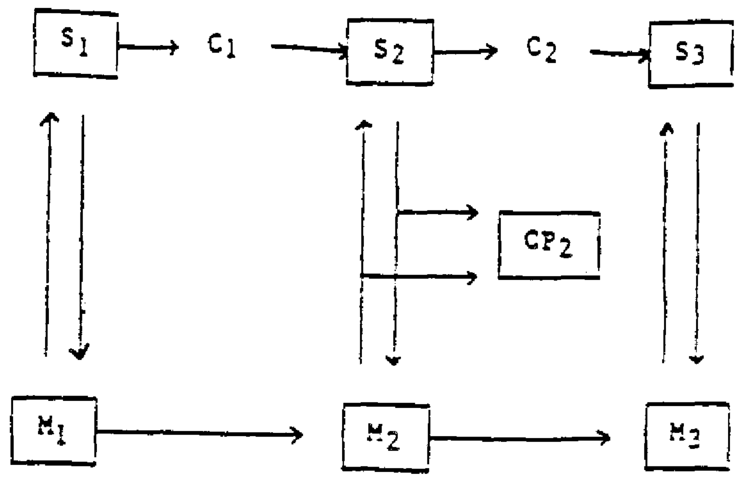


FIG. 2. COMBINATIONS OF IMFORMATION ON CHEMICAL ACCIDENTS



S = Surveys of the Real World

C = Control Mechanisms

M = Models, forecasts, and plans

CP = Comparative analyses of models vs. Real World

Figura 3. Planning Implementation Process