Methods for Assessing and Reducing Injury from Chemical Accidents
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14 Chemical Accidents: Long-Term Health Issues

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14.1 INTRODUCTION

Chemical accidents may be of different types and involve different hazards (Tables 14.1 and 14.2). In general, three main phases of activity follow after a chemical accident (Figure 14.1: (i) the emergency phase, which may be concluded in a relatively short time; (ii) the follow-up phase, which is the real substance of the emergency response and may continue for days; (iii) the rehabilitation phase which may take weeks, months or even years to accomplish. To be successfully and timely performed all these activities require accurate planning before the accident takes place (Figure 14.1).

If the accident is detected when taking place or shortly afterwards (as is likely the case for accidents associated with, for instance, explosions, fires, or derailments), the health impact of the emergency and follow-up phases is related to acute effects, whereas the rehabilitation phase deals with long-term effects.

Even accidents involving clear manifestations may go unnoticed by the community and become manifest only through their impact on health. This was the case of the ICMESA accident at Seveso where a clearly visible cloud was released from the plant, but awareness of the severity of the accident only developed 10 days after the release, when skin lesions began to appear among exposed children.

Regardless of whether or not the accident is self-evident, even in the emergency phase, attention should be paid to some long-term health issues in order not to jeopardize, with improper actions, long-term follow-up. This, however, happens rarely in view of the many other more pressing concerns and needs generally present in an emergency situation.

This chapter deals with long-term health issues of area-wide chemical accidents involving the release of toxic chemicals. It does not discuss the aspects concerning emergency health care.

Table 14.1 Common types of chemical accidents

– Misuse
– Spill
– Fire
– Improper waste management
– Disaster/explosion in a plant or storage facility
– Accident during transportation

14.2 POST-EMERGENCY MEDICAL CARE

Medical rehabilitation follows from emergency care to whatever extent of recovery is possible. In most chemical accidents, treatment of the victims is not likely to be different from the usual treatment for sick patients showing similar symptoms and diseases. If specialized clinical help is needed, it should be provided while 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.

Medicine does its best work by the one-on-one system and, even if the strictly medical aspects are essentially ineffective, personal attention from the doctor and others concerned can have great healing effects.

Table 14.2 Types of chemical accidents which have a higher potential for affecting a neighbouring population

Accident	Hazard
(i) *Events involving flammable material*	
– Fire, no explosion	– thermal radiation – smoke
– Fire in chemical plant	– spread of fire – explosion – release of toxic substances + as above
– Explosion	– blast wave – flying debris – thermal radiation
(ii) *Events involving toxic materials*	
– Slow or intermittent release (e.g. leaking valve) – Rapid release, limited duration (e.g. fracture of pipe) – Massive release (e.g. failure of large storage tank)	– Exposure to toxic chemicals

	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
AFTER THE ACCIDENT	4) Emergency	• Accurate response • Speed of action
	5) Follow-up	• Knowledge of chemical • Fencing-in of the accident
	6) Rehabilitation	• Diagnosis of needs • Implementation • Monitoring • Feedback and adjustment • Information transfer and storage

Figure 14.1 Components of chemical emergency preparedness (from Silano, 1985)

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

1. Treatment according to symptoms of the pathologic process initiated by the toxic substance. According to the severity and evolution of the process, this treatment can be of short or long duration.
2. Treatment (if any) to facilitate the elimination of the toxicant from the body.
3. Discussion about eventual termination of pregnancy in cases of high risk of foetal malformation.

The treatment following the emergency phase should still be a responsibility of the medical staff normally performing 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 poison control 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.

Occupational health services play a major role in the physical rehabilitation of workers subsequent to exposure to chemical agents. If the chemical has affected the respiratory tract causing bronchitis, the rehabilitation is aimed at avoiding the onset of a chronic condition and, eventually, of emphysema: remedial action implies respiratory exercise, bronchial cleaning and prevention of infections. If the chemical has induced asthma, the rehabilitation has to be carefully planned according to whether it is occasional or permanent, and according to the patient's evolution as it is recorded by subsequent medical checks. Specially trained personnel should follow asthmatic patients in the rehabilitation subsequent to acute chemical exposures.

The rehabilitation of patients who suffered renal damage from chemical exposures requires special care for the amount of physical activity allowed to the subject. The rehabilitation of subjects with hepatic damage is very much based on health education and an intervention in life-style factors, such as dietary habits. Neurological damage, such as peripheral neuropathies by TOCP, requires rehabilitation which is essentially motor re-education and physical therapy.

It is obvious that if patients suffer from more than one health effect due to a chemical accident, there is a need for an integrated rehabilitation approach; removal of the subject from hazardous exposure is a prerequisite of any rehabilitation programme.

The psychological and emotional well-being of the population is an integral part of the health. Rehabilitation procedure should recognize this and provide suitable arrangements. The psychological 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 rooted in rumour can continue for many years. If obtained in good time and communicated widely, relevant information on the evolution of the health and environmental impacts of the accident may relieve the anxiety of the population involved.

14.3 HEALTH SURVEILLANCE SYSTEM

A surveillance system should be established as soon as possible after the accident. The establishment of a responsible team is normally the first and key step of the process. The optimum solution for the establishment of the team should emerge from consideration of the possible options and 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.

14.3.1 Purpose

The surveillance system has the main purpose of evaluating:

- the long-term health impact of the accident;
- the effectiveness of post-emergency medical care;
- the possible persistence of a threat to health depending on the environmental contamination caused by the accident.

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

An example may be useful to illustrate this issue. On 6 April 1973 a group of firemen were deployed in the clean-up subsequent to a spill of 1,3-dichloropropene due to a truck accident. Nine of them were treated at a local hospital for symptoms related to the acute toxicity of this chemical. Six years later, two of the nine firemen developed malignant histiocytic lymphoma. The other seven firemen are currently being monitored (Markovitz and Crosby, 1984). The availability of records concerning cases of severe exposures to chemicals, such as the one described in the aforementioned paper, is a tool for a subsequent appreciation of possible long-term health effects.

14.3.2 Information Basis for Planning

In order to establish a surveillance system after a chemical accident, it is necessary to appraise the situation, on the basis of available information and to decide what the main characteristics of the system should be. Ideally, the following information should be available:

1. The nature of the chemical(s) released and its (their) metabolic and toxic properties.
2. People exposed and, possibly, route(s) and extent of exposure.
3. Whether exposure of people to the released chemical(s) has ceased or is still continuing.
4. Medical treatment available to prevent or minimize long-term effects (with emphasis on treatment and/or antidotes specific for the released chemical(s), if any).
5. Available medical facilities and human resources.

In practice, most systems have to be based on incomplete or even contradictory information making the best possible use of whatever information is available. Adjustments should be introduced as knowledge progresses.

14.3.3 Planning

A number of scenarios are conceived which would lead to different approaches in setting up the surveillance system. Two rather extreme scenarios can be used as examples. In the first scenario, only one chemical has been released as a consequence of the accident. Possible long-term effects of the released chemical are well known and the exposed population can be identified by monitoring the level of the chemical in easily obtainable biological specimens (e.g. blood, urine or hair). In such a case, the surveillance system should be focused on the relevant health effect(s) and exposed population.

In the other scenario, several chemicals have been released, some of which are unknown and the exposed population is poorly defined. In such a case a full surveillance is necessary, considering a number of health effects and a population likely larger than that actually exposed; the exposed population should be identified by using, with a conservative approach, any available indicators of exposure. In this case a control population is also necessary to evaluate the results of the surveillance.

As was extensively discussed in the case of populations exposed to toxic chemical wastes (Grisham, 1986), the design of studies concerning the long-term health effects of chemical accidents seldom takes place under conditions which favour the planning of an investigation able to meet the requirements of validity and statistical power. None the less, the results of such studies are likely to influence to a great extent subsequent decision-making processes in public health. The informativeness and the limitations of a study should thus be appreciated at the stage of its design. The amount of confidence put later on in the results of the study should then reflect the inherent validity of the investigation itself.

There are three key aspects in any surveillance system, i.e. the population to be followed, the health data to be gathered, and the organizational features.

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 is 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. Population registers are generally used to define the study base with respect to residency in the affected area; the identification of subjects temporarily residing in the areas requires an active collection of information, which may not always be feasible.

Analytical epidemiological studies imply the assessment of both exposure and outcome at the individual level. This procedure is commonly applied in occupational studies, but it may not always be the case in environmental studies, whereas a geographic assessment of exposure is often performed. It should be noted, though, that any loosening of the criteria of admissibility to the exposed categories will cause a dilution of the association between exposure and health effect (for a review, see Checkoway, 1986).

For accidents involving the release of 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 of an important environmental contamination resulting from the accident).

The impacted area can be broadly defined if the pattern of chemical release is known or can be modelled. Other important information in this respect might be obtained by mapping animal lethality or plant damage (if it has occurred). If the chemical released is persistent in some environmental compartments, an environmental monitoring programme (if feasible) might be very helpful to define the area affected by the accident. In the case where the population has not been evacuated, the monitoring of the released chemical in the food chain, water and/or soil would also be very valuable to understand if the human exposure is actually continuing after the accident.

Once the affected area has been defined, a preliminary identification of the exposed people can be carried out by administering questionnaires. Procedures aimed at the prevention (or at least reduction) of bias in the collection of information by the use of questionnaires have been extensively discussed in the last few years (for a comment, see Siemiatycki *et al.*, 1984). Particularly, if the number of people potentially involved is very high, the temptation to administer highly complex questionnaires should be resisted. Sometimes, it may be sufficient to ask where the person was at the time of the accident and what he/she was doing.

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 toxicokinetics 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.

Obviously, the above-mentioned approaches are not mutually exclusive. Depending on specific circumstances, some of them can be used in a combined or integrated manner; this may prove to be very useful particularly to quantify the exposure of different population groups. However, one should not

overlook that different exposure indicators may give results that are not consistent. For instance, in the case of the ICMESA accident at Seveso the following indicators of exposure were used to define the most affected area: (*a*) chemical determination of 2,3,7,8-tetrachlorodibenzo-dioxin in soil; (*b*) animal mortality; (*c*) incidence of chloracne among the population; and (*d*) modelling of the fall-out pattern of the cloud and administration of questionnaires. The results obtained with the four indicators were remarkably different, possibly because the indicators chosen were relevant for different types of exposure to TCDD occurring to different extents at different times after the accident (Pocchiari *et al.*, 1986).

When for whatever reasons analytical determinations cannot be carried out at the time they are needed, the possibility of taking samples of contaminated materials (e.g. dust, soil, or foodstuff) and biological samples (e.g. blood and tissue specimens) should be considered, in order to carry out at a later date the analyses or to assess other chemicals previously not thought of. The appropriate procedures for storage and transportation of samples should then be adopted.

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 toxic 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). Criteria for choosing the end points of the study should include both *a priori* knowledge of the health effects of the exposure of interest and an evaluation of the feasibility of collecting the relevant information in the population being studied.

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, existence or absence of clinically detectable conditions or of 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. The 'routine' type of surveillance could complement the intensive surveillance on selected groups of people, when a large population is involved. 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 reanalyse every sample, if necessary. It is essential to have well-defined biological hypotheses before starting a programme of specimen collection.

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 study design should consider validity issues, namely how to avoid bias with respect to the selection of subjects, the collection of information on exposure and outcome and the choice of a suitable reference entity. The sample size of the study should be critically evaluated in order to ensure the desired level of precision. The analysis of data should be performed allowing for potential confounding variables. Several computer programs able to perform the analysis of cohort data are now readily available, and can be run both by mainframe and personal computers.

Organizational Aspects

Every possible effort should be done in order to help local health services to re-establish full responsibility for routine diagnosis and treatment. If not available at local level, specialized medical help should be provided. No parallel health system should be developed, unless absolutely necessary. External agencies may help by providing support for training activities and specific methodologies, by performing special clinical toxicological trials and experimental toxicity studies, and carrying out specific research studies with selected groups of people requiring tests that cannot be carried out at the local level.

Collaboration of the team in charge of the surveillance system with local health services and specialized associated clinical services is essential. Such collaboration is more likely to be ensured if representatives of the local health services are present in the team in charge of the surveillance system.

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 sources are likely to be the hospital discharge data and mortality data. These last are generally exhaustively collected and coded. 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 who are admitted to a hospital located outside the area.

Morbidity, malformation and cancer registries may also be created depending on the outcome(s) suspected. Such registers must be submitted to checks concerning the way they actually reflect the occurrence of disease in the population of interest. If reporting is exhaustive, such registers can provide

reliable data on the incidence of the disease(s) and its/their distribution in the various subgroups of the population. Besides providing these figures, which are relevant in terms of descriptive epidemiology, registers can be used as sources of subjects in case-control studies. These last are investigations of aetiologic relevance, since they lead to estimates of the relative risk and of the attributable risk associated with a given exposure.

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 long enough to prove or exclude the occurrence of such effects; in practical terms, this may mean a 30 years or more surveillance project. If no acute effects are detected and no chronic effects are suspected, surveillance should be carried out for several months; if no health effect shows up, surveillance can be discontinued.

14.4 FEEDBACK AND ADJUSTMENT

A systematic feedback and adjustment process must be ensured. The assessment of effectiveness of rehabilitation of people is based on re-evaluation of facts 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 develop strategies continuously for the future as the programme evolves. Any new decisions taken during rehabilitation require some modifications of the works carried out by the rehabilitation teams. This implies a precise role of the team responsible for health surveillance which is also responsible for the work of the different groups.

Continuity of responsibilities should be maintained throughout the entire surveillance 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 adjustment 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.

14.5 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, numbers 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.

14.6 INTERNATIONAL COOPERATION

Several types of accidents may require an international follow-up, e.g.: (*a*) major accidents, and complex and unique accidents; (*b*) accidents close to a border; and (*c*) multinational operations.

International networks to provide for cooperation are essential and are likely to be called upon to play an essential role in rehabilitation of people following these types of chemical accidents. Epidemiologists with practical experience are rare in some countries. Therefore, international cooperation might be particularly helpful in this area.

14.7 CONCLUSION

The actions needed to understand and minimize long-term health effects of chemical accidents are highly complex and require proper timing. Moreover, they require a careful appraisal of the situation and a considerable skilfulness in planning and organizing. It should be appreciated that the conduct of a long-term follow-up implies a remarkable financial burden, requiring a strong budgetary commitment. This effort appears to be justified in the light of the issues presented in this chapter. Inadequate allocation of resources and excessive delays may result in the impossibility of coping with long-term effects of the accident, although retrospective studies may still be possible in order to learn what happened.

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