3 ASSESSMENT OF REHABILITATION NEEDS

3.1 Introduction

3.1.1 Purpose of the Assessment

Before a rehabilitation programme is started there must be a rehabilitation plan. Such a plan can only be formulated after consideration of:

- the probable risks to the population, the environment and the economy if no further action is taken; and

- a preliminary estimate of the costs of rehabilitation and of how the programme will be funded.

An assessment of rehabilitation needs, therefore, must be undertaken to form the basis for a rehabilitation plan.

3.1.2 Objectives

The objective of this chapter is to present a methodology for undertaking an assessment of rehabilitation needs that is applicable to the broad range of chemical accidents considered by the Manual. The methodology must be:

- applicable to short-term episodic releases as well as chronic releases;

- able to address effects on natural resources as well as human health effects; and

- suitable for assessment of carcinogenic health effects as well as non-carcinogenic effects.

(A list of the different attributes by which chemical accidents can be classified is further described in Annex 3A.)

3.1.3 Structure of Chapter

The chapter is presented in three sections.

o Section 3.2 describes the general concepts to be considered in the overall assessment process and presents the phases of work to be undertaken in developing a rehabilitation plan.

o Section 3.3 describes a methodology for assessing the risk to human health and natural resources resulting from a chemical exposure.

o Section 3.4 describes how rehabilitation goals based on acceptable human health risk and natural resource damage can be used to select an appropriate rehabilitation plan.

3.2 Assessment Approach

3.2.1 Assessment Process

To provide a framework for the overall assessment process, four phases of work can be defined.

- o Phase 1. Initial assessment.
- o Phase 2. Data collection.
- o Phase 3. Assessment of health risk and damage to natural resources.
- o Phase 4. Development of a preferred rehabilitation strategy.

Each of these phases is further outlined in the following sections.

3.2.2 Phase 1. Initial Assessment

The purpose of the initial assessment is to develop a preliminary understanding of the accident based on available data, and to determine additional data needs for a more complete assessment.

The initial assessment can be considered in three steps: data collection; interpretation; and determination of additional data needs to develop further the initial interpretation.

(a) Initial Data collection

Available data must be collected to characterise the accident to the maximum extent possible so that a profile of chemical release to the environment is developed including information on:

- the source of release;
- the chemical released;
- the amount of chemical released and the release dynamics;
- the environmental and toxicological properties of the chemical;
- the area affected; and
- the receptors potentially exposed.

Data on the accident can typically be assembled by a combination of site reconnaissance and data sources from the secondary literature (see Environment Canada, 1983 for a useful compendium of information suitable for initial assessment). In many instances, emergency personnel who have dealt with the first phase of a chemical accident response will be a valuable source of data. Whenever possible, site reconnaissance should be conducted initially with the emergency response personnel who have had first-hand experience of the accident site.

(b) Data interpretation

It is then the rehabilitation manager's job to assess the quality of the information collected, to identify gaps and to make an initial interpretation of the data. Human health effects are usually the most pressing concern in the initial assessment, so the most important interpretative effort is to relate the levels of contamination resulting from the accident to the potential toxicity of the chemicals released.

(c) Diagnosis

Based on the initial interpretation of available data, there will usually be formed a preliminary hypothesis as to the nature and severity of the contamination resulting from the chemical accident. To test and/or define more precisely any such hypothesis, additional data will likely be required.

3.2.3 Phase 2. Data Collection

In the second phase of work, data will be collected which in large part will be used as the basis for estimation of health risk or natural resource damage in Phase 3. The estimation of risk is typically developed from two building blocks: assessment of exposure to chemical contaminants and evaluation of the effects of exposure. The type of data to be collected can correspondingly be placed in two groups as shown in Table 3.2(a). Each of these types of data is discussed briefly below.

Table 3.2(a)
Data Collection for Assessment Programme

Exposure	Effects
o Environmental sampling o Environmental fate and transport data o Site characteristics	o Toxicological data o Health survey o Survey of other effects, e.g. ecological damage

(a) Environmental sampling

Environmental sampling may be needed to define more precisely the extent of contamination. In developing a sampling plan, careful consideration should be given to:

- the objectives of the sampling plan and the representativeness of the results likely to be obtained;

- the feasibility of using indicator chemicals, when dealing with mixtures of chemicals, in order to reduce analytical costs, and

- quality control and quality assurance at all stages of the process including sample taking, preservation, chain of custody and analytical techniques.

(b) Environmental fate and transport data

Fate and transport data for the chemicals of concern will be required in situations where predictive modelling is to be used to estimate the rate and magnitude at which environmental contamination may spread. A discussion of the types of environmental fate and transport processes is provided in Annex 3B.

(c) Site characteristics

The potential severity of the effects of a chemical accident will be influenced significantly by the nature of the receptors in the immediate vicinity of the accident site. A detailed knowledge of the local land use, population and ecological units is therefore of fundamental importance.

(d) Toxicological data

Toxicological data for the chemicals of concern will typically be required for any detailed analysis of human health effects or ecological damage.

(e) Health survey

A health survey may be appropriate to determine if there is a clear relationship between environmental contamination and observed human health effects.

(f) Survey of non-human health effects

A survey of non-human effects may also be appropriate. For example, plants can provide an early indication of environmental contamination.

3.2.4 Phase 3. Assessment of Health Risk or Resource Damage

The assessment of risk to human health or damage to natural resources is perhaps the most fundamental phase in the overall assessment of rehabilitation needs. It can be considered in four distinct steps: the assessment of exposure to chemicals released; the evaluation of the effects resulting from that exposure; the combining of the two elements to estimate health risk or resource damage; and the evaluation of the significance of the estimated risk.

(a) Exposure assessment

Exposure assessment involves describing the nature and size of the various populations exposed to a chemical agent and the magnitude and duration of their exposures. The assessment could concern current or predicted exposure.

(b) Hazard assessment

Hazard assessment involves gathering and evaluating toxicity data on the types of health effect, ecological damage or other adverse effect that may be produced by a chemical, and how the magnitude of such effects is related to the amount of exposure.

(c) **Risk estimation**

In the risk estimation step, a quantitative measure of risk is obtained by comparing predicted exposure with the exposure-response relations developed in the hazard assessment.

(d) **Risk evaluation**

For human health effects, risk evaluation compares the predicted risk to some "acceptable" level of risk.

For natural resource damage, a broader range of adverse outcomes may be considered, so that a monetary measure of damage is suggested as a more appropriate method to weigh natural resource damage.

The process of evaluation for human health risk and natural resource damage is described in more detail in Section 3.3.

3.2.5 Phase 4. Development of a Preferred Rehabilitation Strategy

The final phase in the assessment of rehabilitation needs is the development of a preferred rehabilitation strategy. Three steps are envisaged here: development of rehabilitation goals, initial screening of alternative rehabilitation methods and a process of more detailed analysis and finally selection of the most appropriate rehabilitation strategy.

(a) **Development of rehabilitation alternatives**

Development of rehabilitation alternatives should be based on goals for reduction of risk to human health and restoration of natúral resources. In practice, compromises may be necessary in setting such goals to allow for the limitations of irreversibility or time for ecosystem restoration.

(b) **Screening of alternative rehabilitation methods**

To select a preferred rehabilitation strategy, an intermediate step should be to screen the alternatives to identify those rehabilitation methods that would be appropriate for more detailed evaluation.

(c) **Detailed evaluation of rehabilitation alternatives**

Each alternative method should be evaluated by consideration of technological, public health, natural resource/environmental, institutional and cost factors.

A more detailed discussion of the evaluation process is provided in Section 3.4.

(d) **Selection of preferred strategy**

The final selection is based on the weighing of the various factors to arrive at the most cost-effective solution.

3.3 Risk Assessment

3.3.1 Principles of risk assessment

The risk assessment provides a more in-depth treatment of the initial assessment undertaken in Phase 1. Risk can be defined as the probability of an adverse effect as a result of exposure to toxic substances. Adverse effects can be either to human health or to the natural resources, i.e. non-human.

The process of risk assessment can be characterised in various ways (see NAS, 1983; WHO 1983). For the purposes of this manual, we have chosen to characterise the risk assessment process in the following steps:

- exposure assessment;
- hazard assessment;
- risk estimation; and
- risk evaluation.

The overall process encompasses both scientific activities on the estimation of risk, as well as socioeconomic considerations in risk evaluation. These aspects ultimately are combined in the process of risk management by which a rehabilitation strategy is developed.

While a distinction can be made between the scientifically based process of risk estimation and the political activity of risk management, it is important ot ask that risk assessment is not exclusively scientific procedure. There is no question that risk assessments are based largely on the results of objective information derived from scientific studies, such as bioassays and epidemological studies. However, risk assessment today is rarely a matter of applying objective scientific rules of inference. This is because there are usually gaps in knowledge that a risk assessor can only bridge by makimng assumptions tht cannot strictly be deduced from current scientific consensus. Such value judgements should bemade explicitly so that it is clear on what assumptions the risk assessment is based. Thus, both qualitative and quantitative aspects are considered in the risk assessment process.

3.3.2 Exposure Assessment

Knowledge of the routes, magnitude and duration of exposure to environmental chemicals is the first component of risk assessment. Human exposure is assessed typically in terms of the dose of chemical taken into the body, commonly in units of milligrams per kilogram of body weight per day. For certain gaseous pollutants, particularly those which act as irritants, exposure may be assessed in terms of the concentration to which an individual is exposed, commonly in milligrams per cubic metre or parts per million, and the time of exposure. For non-human receptors, similar approaches apply; for aquatic species the aqueous concentraion, commonly in milligrams per litre, is the usual measure of exposure.

In the context of a chemical accident, the starting point for assessing exposure is the profile of environmental releases develped in the Initial Assessment Phase (see 3.2.2). For example, a release of gaseous pollutants impacting a neighbouring community might be characteised by:

- the chemical compound released;
- the duration of the release; and
- the magnitude of the release.

Or, the leaching of a hazardous waste site to contaminate an estuarine fishery might be characterised by:

- the composition of the leachate; and
- the flow and concentration of leachate into the estuary.

The next step is to identify the receptors of concern anmd the possible routes of exposure. Three routes, inhalation, absorption and ingestion, exist via which humans can become exposed to pollutants in their environment. Similar considerations apply to exposure of ecological systems, although other routes of exposure may also be important e.g. root uptake for plants. Pollutants can be present in various environmental media such as air, surface water, groundwater, and soil. Through direct contact with these media (or indirect contact via the foodchain) receptors can inges, inhale or absorb pollutants and thus become exposed. If the concentrations of pollutants in each of these media are known or can be predicted and the extent and frequency of contact with each is known, then exposure to each pollutant can be estimated. To this end, environmental fate and transport models can be used to predict the concentrations of pollutants in the various environmental media likely to result from a chemical accident (see Annex C for a discussion of environmental fate and transport process).

To calculte the dose that would result form contact with these pollutants, certain standard conventions are commonly applied. These conventions assume average values for the intake of food, water, etc., and also make assumptions regarding the absorption of pollutants within the organism of concern, human or otherwise. Estimates of dose or pollutant concentration and exposure time calculated in this way can be applied to both short-term and long-term exposure assessments.

3.3.2 Hazard Assessment

All chemical substances, whether natural or man-made, hae the potential to cause some form of biological injury, disease or death under certain conditions of exposure. The term used to describe this inherent potential is toxicity, and the purpose of the hazard assessment phase of risk-assessment is to colleect and evaluate information on the inherent toxic properties of the chjemicals of interst. This information may relate both to acute and chronic toxic effects. The approach to hazard assessment is described separately for human receptors and ecosystems.

(a) Human health hazard

Information on chemtoxicity can be collected from two principal souirces: epidemiological or clinical investigations, and experimental studies involving laboratory animals or other biological systems. In addition to identifying the types of toxicity associated wiht a substance, it is also necessary to identify dose-response relationships. The frequency with which toxic effects appear in an exposed population (i.e., the risk) increasees with increasing exposure or dose. In many cases, the types of toxic effects change as exposure increases, becoming more severe with increasing exposure conversely, less severe with decreasing exposure. Thus, it is important to understand how the nature and magnitude of risk relate to any given dose.

A major dose-response issue is that of thresholds. A threshold dose is that which must be exceeded before a toxic effect is observed. The appearance of most toxic effects requires that a threshold be exceeded, although for some, notably carcinogenic effects, there appears to be a basis for rejecting threshold hypothesis. In fact, carcinogenic risk assessment, as currently practiced, generally assumes the absence of thresholds. It should be noted, however, that this premise may not hold for all carcinogens.

One of the critical uses to which dose-respnse data are put is the ifentification of the dose at which no advrse response is observed in a population exposed to a toxic substance. This dose (called the "no-observed adverse effect level," NOAEL) may approximate a threshold dose for the population under study, and is generally taken as the starting point for risk assessment for chemicals that are assumed to operate by a threshold mechanism (National Research Council, 1980). This general approach applies both to acute and chronic exposures, although the dose-response data may be determined from different types of studies. Data for chronic exposures are generally derived from animal studies, although in some cases, particulary for exposure by inhalation, human data may be available from occupational settings. For acute exposures, human data are usually available from clinical tests or accidental exposures, supplemented as necessary by informatoion from animal studies.

For carcinogens, the dose-response data are usually treated differently. To predict low dose risk from high dose/high risk data, which is the usual situation, it is necessary to apply certain mathematical models to the dose-response data. These models allow prediction of low dose risks, and their application yeilds an estimate of cancer risk per unit of dose (e.g., incidence of cancer at a dose of 1 mg/kg body weight/day, for continuous lifetime exposure.

The hazard assessment phase of risk assessment thus results in a presentation of NOAELs for non-carcinogens, and of estimates of risk per unit dose (unit risks) for carcinogens.

(b) Natural resource damage

The principles involved in assessing potential damage to natural resources are essentially parallel to those described for human health with a number of significant differences. First, the extrapolation from test species for which data are available to the species of voncern may involve less uncertainty than for animal to human extrapolation. However, environmental damage is rarely restricted to or focussed on a single species (although this may occur for certain commercially developed resources, eg. crops or fisheries). An ecosystem consist of a set of physical, chemical and biological components that interact in complex ways.

While the first of these differences may simplify the hazard assessment, the second introduces additional complications because of the various responses that environmental polutants can cause. Such responses include effects on:

- diversity;
- levels of productivity and biomass;
- resistance and resilience;
- interaction of species; and
- flows of energy and essential nutrients.

To the extent possible, develpment of a natural resource damage function shoul dtake account of these factors, if not quantitatively, then at least qualitatively. An ecorisk model discussing these aspects is described in a recent report on risk-cost analysis techniques for hazardous waste management (see ICF Inc, 1984).

3.3.4 Risk estimation

Having evaluated the inherent hazard posed by a chemical agent, and the routes, magnitude and duration of the exposure, a quantitative measure of risk may be developed. A distinction is generally made here between the way in which risk is estimated for exposure to carcinogens adn exposure to non-carcinogens.

(a) Non-carcinogens

For chronic exposures to non-carcinogens, it has become the practice to divide the experimentally-determined NOAEL by a large "safety factor" to estimate acceptable human doses. The appplication of the safety factor is based on the notion that there is likely to be a much wider range of susceptibilities in the human population than there is in the test animal group from which the NOAEL is obtained. The choice of safety factors depends on the nature and uncertainties of the toxicity test data. If the NOAEL was derived form a well-conducted animal chronic toxicity study, and has been carefully identified, the usual safety factor ffor estimating an "acceptable daily intake" (ADI) for humans is 100. Larger safety factors are commonly introduced when experimental data are lacking or limited, or when the effects of exposure are especially serious (Calabnrese, 1983).

Risk characterization for non-carcinogens thus takes the form of determining the margin-of-safety (MOS) - the numerical valued derived when the experimental NOAEL is divided by the human dose. Under this system, the smaller the value of the MOS,the larger the risk. A similar approach is appropriate for estimating natural resource or ecological damage with safety factors selected on a casey be case basis.

(b) Carcinogens

For chronic exposures to carcinogens, the risk is characterized as the risk per unit dose or unit cancer risk multiplied by the actual daily lifetime dose experienced. In this case, an explicit risk is estimated, which takes values between zero and one.

3.3.5 Risk evaluation

In evaluating the significance of the estimated risks, separate approaches can be defined for human health effects, and for damage to natural resources. In evaluating human health effects criteria can be developed for determining acceptable health risks, albeith using separate methodologies for carcinogens and non-carcinogens. For natural resources an acceptable level of damage may be hard to define in terms of adverse impacts on particular species or ecosystems, so that an alternative approach suggested there is to use an economic evaluation methodolgy.

(a) Risk criteria for non-carcinogens

The acceptability of risk for non-carcinogens depends on the magnitude of the remargin of safety (Mos). If there is virtually no MOS, it might be concluded that many members of the exposed population are at high risk of experiencing the form of toxicity experienced by the test animals at doses above the NOAEL. At a small fraction of the NOAEL, it is likely that the risk is very low and may be zero, although there is no practical way to determine whether this is actually the case.

(b) Risk criteria for carcinogens

The definition of acceptable risk for carcinogens is a matter of judgement or policy rather than a scientific determination. The use of numerical estimates as decision-making tools for separately significant risk from insignificant risk has some precedent in determining rehabilitation needs. For example, the soil clean up standards set by the Dutch government are based on a lifetime cancer risk of 10^{-2} (Moen et al, 1986). Similarly the public health criteria used as the basis for the US Environmental Protection Agency Superfund Cleanup standards are typically risk levels in the range 10^{-4} to 10^{-7}, with 10^{-6} seemingly enjoying some degree of preference (USEPA, 1985). Risk levels in this range have also been used as the basis for water quality criteria and regulation of food additives in the United States.

(c) <u>Economic evaluation for natural resource damage</u>

In considering rehabilitation of chemical accidents that have resulted in environmental or natural resource damge, economic evaluation may provide a useful basis in determining the extent of cleanup to be undertaken, placing monetary values on natural resource losses explicitly weights the type of resources in terms of their importance to society and is controversial by its very nature. Economists attempt to avoid these concerns by selecting those values that reflect society's preferences rather than their own (see Environmental Law Institute, 1984). The steps undertaken in an economic evaluation can be summarised as:

- measure physical damages to the resource, ie riks estimation;
- measure impact of damage on resource use; and
- place monetary value on damage.

The process begins with the demand for the services of the resource, which can be classified into a number of categories including:

- consumptive recreation (sport fishing, hunting etc.)
- non-consumptive recreation (bird watching, boating, etc.));
- preservation;
- commercial fishing;
- waste treatment;
- commercial development;
- agriculture;
- forrestry; and
- extractive activities (e.g. minerals, oil).

The above categories can be divided into two groups: public uses such as recreation and commercial uses such as commercial fishing, facilities and development. In the first group the public directly consumes or demands the service as a final product, e.g. fish in commercial fishing or waste assimilative capacity for waste treatment.

Estimating the value of public resources is more difficult than estimating that of comercial uses since public uses are generally not traded or priced in a marketplace. However, implicit or indirect prices for these services can estimated, and values of commercial resource uses can be estimted by consideration of the demand for the final product generated from that resource (see Environmental Law Institue, 1984). Examples of the economic damage sustained to commercial activities including agriculture, industrial activities are included in the Parliamentary Commission of Enquiry's report into the Seveso accident (1978).

3.4 Development of a Rehabilitation Strategy

3.4.1 Risk management approach

From the risk assessment process described in Section 3.3, the problem posed by a chemical accident can be defined either in terms of the risk to human health or the monetary damage to natural resources. This problem definition can then be used as the basis for establishing goals for reducing health risk to acceptable levels or establishing the importance of restoration of natural resources. In practice complete restoration may not be a realizable goal; as an extreme example, restoration of a climax forest ecosystem could only be achieved with the passage of a long period of time. On the other hand, restoration of a coastal fishery could be essentially complete if the source of pollution was eliminated and the fishery restocked.

Having established realizable goals for rehabilitation, the best strategy for achieving the desired level of rehabilitation must be selected. In practice other factors must also be selected in developing a preferred rehabilitation strategy, e.g. cost, technological feasibility and institutional requirements. This is essentially a risk management process whereby the desired rehabilitation goals must be balanced against the other factors. The following steps can be identified in undertaking the risk management process (see US EPA, 1985):

- development of rehabilitation alternatives;
- initial screening of rehabilitation alternatives;
- detailed evaluation of rehabilitation routes; and
- selection of preferred rehabilitation strategy.

Each step is described further in the following sectons.

3.4.2 Development of rehabilitation alternatives

Rehabilitation alternatives should be selected that will:

- address the specific site problems and pathways of contamination; and
- meet rehabilitation goals and objectives.

Site problems can generally be placed in one or more of the following categories:

- air pollution;
- surface water infiltration or contamination;
- leachate generation and contaminated groundwater;
- gas migration;

- presence of chemicals in drums, lagoons, etc.; and

- contaminated water supply and sewer lines.

As a first step, general response actions should be considered without necessarily identifying specific technologies, including the "no action" alternative as a baseline against which other measures can be measured. Examples of general response actions include no action, containment/control of off-site migration, removal of contamination source, alternative drinking water supply, relocation of receptors, etc.

Possible technologies should then be identified for each general response action identified (see Chapters 4 and 5 for discussion of rehabilitaition technologies), and a preliminary screening of technologies based on site conditions. A series of rehabilitation alternatives can then be assembled based on the remaining feasible technologies.

3.4.3 Screening of rehabilitation alternatives

Screening of remedial alternatives should next be undertaken to eliminate those schemes that:

- do not adequately reduce risk to human health or natural resources; or

- are much more costly than others without providing significantly greater benefits.

In considering risk to human health and natural resources, schemes that are responsive to the rehabilitation goals, may also generate other adverse impacts. For example, excavation of a hazardous waste site to remove a source of groundwater contamination might pose an unacceptably high risk to neighbouring residents because of dust generation. Where major impacts are identified, the rehabilitation alternative should be eliminated.

The remaining alternatives are then screened on the basis of both capital, operating and maintenance costs. The costs should reflect site-specific conditions, and be undertaken at an approximate level of detail sufficient to permit order of magnitude cost differences to be identified. A present worth analysis approach to costing is recommended.

3.4.4 Detailed evaluation of rehabilitation alternatives

The next step in the development of a preferred rehabilitation strategy is the detailed evaluation of rehabilitation alternatives solution. The evaluation process should address the following set of factors:

- technological factors;

- human health risk;

- natural resource damage;

- institutional factors; and

- cost.

Each of these factors is briefly addressed below.

(a) Technical evaluation

The technical evaluation of alternatives focuses on performance reliability, ease of implementation and safety.

- o Performance should be considered both in terms of the ability to perform the intended function, e.g. treatment, containment, etc, and useful life since most technologies with the exception of destruction will deteriorate with time.

- o Reliability is an important factor both in the consideration of operating and maintenance costs and in the proven performance of the technology at other chemical accident rehabilitation sites. For example, the use of underground barriers for containment has not always been successful in adequately limiting pollutant migration.

- o Ease of implementation refers to the relative ease of installation and the time required to achieve a given level of response. The time requirements can be considered as both the time required to implement a technology and the time required before results are actually realised.

- o Safety should include both short-term and long-term threats, e.g. fire, explosion, to those workers on-site as well as to the safety of nearby communities and environments.

(b) Human health risks

Evaluation of public health risks associated with each rehabilitation alternative should be undertaken in a manner paralleling the initial risk assessment described in Section 3.3. The alternatives should be evaluated against the goals for risk reduction established at the beginning of the risk management process (see 3.4.1), and where appropriate the rehabilitation alternative may be modified to improve compliance with the desired goal. Comparison of projected environmental concentrations to appropriate ambient standards should also be undertaken.

(c) Natural resource impact

As for human health risks, evaluation of natural resource impact associated with each rehabilitation alternative should be undertaken in the same way as the baseline risk assessment described in Section 3.3. The evaluation should include short-term effects as a result of construction activities as well as the long-term effects associated with the immediate reason for taking action at the site. Again, comparison of projected environmental concentrations to appropriate environmental standards should be undertaken.

(d) Institutional factors

Institutional factors include primarily, the consideration of: licensing or permitting needs, and the impact on public relations of an accident rehabilitation.

- Licensing or permitting requirements may pose obstacles to implementing otherwise practicable alternatives, for example transfrontier movement or off-site disposal of hazardous waste.

- Public or community relations should be an integral part of accident rehabilitation. In evaluating alternatives, consideration should be given to public opinion and steps taken to address public concern and incorporate citizen input to the extent feasible.

(e) Costs

A more detailed cost evaluation should be undertaken than that prepared in the screening of alternatives, including distribution of costs over time.

Present worth analysis should be used so that rehabilitation alternatives can be compared on the basis of a single figure representing the amount of money that, if invested in the base year and disbursed as needed would be sufficient to cover all costs associated with the rehabilitation action over its planned life. It is also recommended that each cost should be evaluated for effects of variations in assumptions by using sensitivity analysis.

3.4.5 Selection of preferred strategy

Having evaluated each of the rehabilitation alternatives against the evaluation factors described above, the final step in the process is to select a preferred strategy. The diversity of site characteristics, the mass of information assembled and the range of factors that must be considered makes evaluating rehabilitation alternatives a difficult process. In this context, decision-making cannot be made by applying a deterministic decision rule. Rather, a judgemental weighing of the results of the evaluation process, the relative importance of each evaluation process and the relative importance of each evaluation factor must be undertaken. In so doing the specific circumstances of the chemical accident must be taken into account.

To simplify the decision-making process and to enable it to be presented more clearly, a matrix approach is suggested as an appropriate way of summarising the information (Hoogendoorn and Rulkens, 1986). A typical matrix format is shown in Figure 3.4(a).

Figure 3.4(a)
Matrix Format for Evaluation of Rehabilitation Alternatives

Rehabilitation Alternative	Evaluation Factors: Technical	Human Health Risk	Natural Resource Impact	Institutional	Cost
1					
2					
*					
*					
n					

It may also be appropriate to introduce formal weighing factors to make the decision-making process more explicit. In any event, this approach provides a systematic framework for arraying and considering the information assembled to select the most cost-effective rehabilitation strategy.

REFERENCES TO CHAPTER 3

United States Environmental Protection Agency (1985). Guidance on Feasibility Studies under CERCLA.

Environmental Law Institute (1984). The Use of Economic Analysis in Valuing Natural Resource Damage. Prepared for the National Oceanic and Atmospheric Administration.

Environment Canada (1983). Technical Information for Problem Spills. Prepared for Environmental Emergency Branch by M M Dillon Limited.

Hoogendoorn, D and Rulkens, W H (1986). Selecting the Appropriate Remedial Alternative: A Systematic Approach. In Contaminated Soil, eds Assink, J W and Van Den Brink, W J. Martinus Nijhoff Publishers, Dordrecht.

Parliamentary Commission of Enquiry (Italy) (1978). Seveso. The Escape of Toxic Substances at the ICMESA Establishment on 10 July 1976 and the Consequent Potential Dangers to Health and the Environment due to Industrial Activity. Translation by the UK Health and Safety Executive.

Moen, J E T, Cornet, J P and Evers, C W A (1986). Soil Protection and Remedial Actions: Criteria for Decision Making and Standardisation of Requirements. In Contaminated Soil, eds Assink, J W and Van Den Brink, W J. Martinus Nijhoff Publishers, Dordrecht.

ICF, Inc (1984). The RCRA Risk-Cost Analysis Model Phase III Report Chapter 4. Ecorisks. Prepared for the US Environmental Protection Agency, Office of Solid Waste.

World Health Organisation (1983). Risk Assessment and its Use in the Decision Making Process for Chemicals Control. Report on a Planning Consultation ICP/RCE 903 (28). ULm 14-16 November, 1983.

National Academy of Sciences (1983). Risk Assessment in the Federal Government: Managing the Process. National Academy Press. Washington D.C., 1983.

ANNEX 3A

CLASSIFICATION OF CHEMICAL ACCIDENTS

3A.1 Introduction

Accidents involving the release of potentially toxic chemicals can be classified and reported for many different purposes and according to a number of different criteria. This annex deals with a global approach to classifying chemical accidents that is intended to identify and define data which should be known and reported in relation to any accident. Eleven main categories of information for classifying chemical accidents are identified in the following sections.

3A.2 Source

Accident sources may be divided into a number of categories including:

- production processes;
- transportation;
- services;
- storage; or
- management of municipal, industrial and hazardous wastes.

Each of these categories can be divided further into sub-categories, based on the type of chemical or industrial sector.

3A.3 Apparent Cause

In this context **cause** means the physical event leading to some release of chemical(s) into the environment. Once again a number of categories can be identified including:

- collision and/or sinking;
- derailment or crash;
- pipe leak;
- leaking landfill;
- process upset; or
- misuse of chemicals.

3A.4 Apparent Reason

In this context **reason** means the human, natural, or mechanical factor causing the event. Possible categories include:

- deliberate negligence;
- operator error;
- weather conditions, e.g. ice or frost;
- road conditions;
- fire;
- explosion; or
- equipment failure.

3A.5 Site of Accident and Area Affected

Frequently more than one category is relevant for describing the site and area affected by a particular accident site area affected. The location of an accident may be described as in the air, water (navigable, surface, underground, domestic supply), or on land. Similarly the area affected may be related to a road, railroad, urban area, village or town, industrial or agricultural area.

3A.6 Amount of Chemical(s) Released and/or Recovered

The amount of chemical(s) released and/or recovered can be expressed as weight (e.g. in metric tons) or volume (e.g. litres). The significance of the amount released is related to the toxicity and the degree of hazard posed per unit (mass) released.

3A.7 Properties of Chemical(s) Released

Chemical properties may be classified in a number of different ways. One approach is to use a classification based on the system used for labelling chemical substances being marketed. This system is useful when properties of the chemical(s) can be obtained from the label on container(s). Such descriptions include explosives, gases, radio-active substances, oxidisers, highly flammable substances, toxic substances, etc.

3A.8 Dynamics of Chemical(s) Release

The dynamics of releases of chemicals can differ widely, for example from the rapid release of an explosion to the slow leaching release from a landfill site.

A fundamental difference between these situations is related to emergency response and rehabilitation. The time available to deal with a contaminant released through explosive force is much shorter than the time available to address the slow spread of a contaminant through the ground. This type of consideration relates not only to the time available for response but also to the extent of contamination and has a special importance when mapping possible rehabilitation zones.

Alternative or in some cases complementary classification systems may focus on the environmental behaviour of the chemical, for example:

- does it sink or float in water;
- is it soluble;
- how dense is the vapour;
- how mobile is the chemical in soil.

In some circumstances an explosive release may be less detrimental than a more controlled release. The Mississauga train derailment of a chlorine tanker, for example, could have been very much more serious had it not been for the fact that the force of the derailment caused an explosion of an adjacent propane tanker, which in turn produced a significant thermal updraft. This updraft carried the chlorine high up into the atmosphere and thus prevented it from "rolling out" and causing more serious exposure for residents in their homes and cars.

3A.9 Toxicity of Chemical(s) Released

The toxicity of a chemical (or mixture) can be classified according to its effect on plants, animals or humans. The response caused can also be of value in classifying the toxicity of a material, for example as allergenic, neurotoxic, hepatotoxic, mutagenic, teratogenic or carcinogenic.

3A.10 Main Routes of Exposure and Health Impact

Human exposure may occur through:

- inhalation;
- ingestion;
- absorption through skin, mucosae and eyes; or
- a combination of these routes.

The resulting health effects should be classified in terms of their nature, duration, reversibility, degree and extent. Chemical accidents may cause immediate or delayed effects. Delayed effects are more difficult to relate to the accident than the immediate ones, since they require clinical and epidemiological surveys which may last for many years after the accident.

An epidemiologic approach is usually required to estimate the number of people in different exposure categories. The exposure categories may be simply exposed or non-exposed, or different degrees of exposure may be considered, including "suspected exposure". Essential data about age- and sex-structure of the different exposure groups should be available to standardise rates and risks.

Diseases existing in the population prior to the accident should also be noted. The risk to various populations is not only related to exposure but also to their vulnerability (state of health, age, sex) at the time of the accident.

3A.11 Environmental, Social and Economic Impact

Chemical accidents may impair the functioning of ecological systems, and the human activities that depend on them. Further impacts may be felt in the socio-economic or cultural systems due to the accident's disruptive nature. All these effects should be classified in terms of their nature, magnitude, duration and prospects for reversibility.

- **Nature of effects.** Effects on ecosystems and natural resources may result in the contamination of ecosystem flows (e.g. water, air), soil-microorganisms, or vegetation. It may also result in the alteration of species patterns (e.g. loss of diversity), succession rate, or land form. Human activities dependent on these systems may also be impacted significantly, e.g. fisheries, agriculture, tourism, etc.

- **Magnitude of effects.** The ecosystem may be affected to various extents including complete local destruction or contamination, or partial system destruction or contamination. In a similar way, the effect on the socio-economic system may result in disruption to the individual, component or sector or the more serious economic or social collapse.

- **Duration of effects.** Adverse effects may occur immediately and last for only a short term. Alternatively, they may have medium-term consequences resulting in gradually increasing, constant, or gradually decreasing effects, or even effects which recur periodically. Finally, the effects may be of a long-term or permanent nature.

- **Quality of effects.** A further important consideration in rehabilitation is that some or all of the effects may be reversible (restoration theoretically possible); non-reversible (permanent damage sustained); or they may be amenable to some form of practical rehabilitation.

3A.12 Level of Resources Required for Rehabilitation

The method of classification presented here is based on an approach developed by Jones et al. (WHO Interim Document 1) in order to define several schematic contingency plans. Four levels of accident sensitivity are defined as follows.

- **Level I (operator level).** An accident where the adverse effects are limited to the confines of one facility (such as a plant, railway station, storage depot, farm, gas or oil pipeline booster stations and/or terminals, etc) and where rehabilitation can be performed within that area by the operator on the site.

- **Level II (local/community level).** This involves an accident where the effects extend to the community, but where rehabilitation can be performed with the resources of that community, plus resources of the plant or industry involved.

- **Level III (regional/national level).** This may be a larger and/or more serious accident or it may be simply that it occurred at the border between two jurisdictions (regions or communities) within one nation or country. This may be described as an inter-jurisdictional accident, and rehabilitation may be handled with the resources available at the regional or national level employing also the resources of the communities and industries involved.

- **Level IV (international level).** This is a complex accident exceeding the boundaries or resources of one nation. It may be a very large-scale national disaster or it may be a unique event requiring special skills or facilities not available in that country, and/or it may simply be a small accident which occurs close to the border of a neighbouring country. The last type of rehabilitation may be performed using national resources, but the management of the response may be undertaken by an international team (two or more affected nations) established for the purpose.

ANNEX 3B

ENVIRONMENTAL FATE AND TRANSPORT PROCESSES

A chemical's entry into transport through, and eventual fate in the environment, depend on its physical-chemical properties (i.e. rate of vaporisation, partition coefficients between environmental media, and chemical reactivity) as well as on the physical and chemical properties of the environment. Taken together, chemical and environmental properties define both transfers between media - the atmosphere, hydrosphere, lithosphere, and biosphere - and degradation within an individual medium. If the chemical and physical properties that influence the movement and lifetime of chemicals within the environment are well understood, the concentration of a chemical at any point in the system can be estimated.

The distribution of a substance in the environment (the atmosphere, surface waters, and groundwater) is influenced by its own physical-chemical properties as well as those of the medium it enters. Movements of chemicals within and between media, as well as degradation of chemicals, are continuous processes. The ease with which chemicals move within and between media is termed mobility. Once a chemical enters a fluid medium such as air or surface water, its dispersion is generally rapid. Movement within a medium is termed intraphase mass transfer, whereas movement of chemicals between two media is referred to as interphase mass transfer. The latter includes processes such as volatilisation, biotic and abiotic absorption, wet and dry deposition, bioconcentration, etc.

Dispersion of a chemical is not only a function of mass transfer, but also of the chemical's stability in any given environment. Environmental persistence, as a measure of this stability, is a function of the chemical processes that produce transformations of a chemical. The reaction rates of such processes directly affect the lifetime of a chemical in the environment and within a medium. Major mechanisms which reduce the amount of concentration of a chemical in the troposphere (the layer of atmosphere nearest the earth roughly 8 km thick) include hydroxyl radical reactions, ozonolysis, reactions with other radicals, and photolysis. For a wide variety of chemicals the most important removal processes in the troposphere are reactions with hydroxyl radicals and ozone.

Important reactions for surface water environments include: hydrogen abstraction, oxidation/reduction, hydrolysis, photolysis, and biodegradation. Chemical reactions that occur in groundwater are similar to those occurring in surface water since both media represent aquatic environments. However, the absolute rates of these reactions differ substantially in ground and surface water. Generally, hydrolysis is most important as a degradative mechanism in groundwater systems. Environmental processes and their relationship to chemical movement are shown in Table 3B.1. Not all processes operate in a given medium and often a single process dominates the total rate of removal and distribution in a given medium.

To give quantitative meaning to the concepts of persistence and mobility, it is useful to define these concepts in terms of a half life for loss of a chemical due to the physical and chemical processes that occur in an environmental medium. The half life of a chemical, the time period over which the concentrtion of a chemical falls to one-half its original value within an environmental medium, is a function of the sum of the rates of all removal processes and is expressed as

$$T_{\frac{1}{2}} = \ln 2/k_T$$

where $T_{\frac{1}{2}}$ is the half life, ln 2 is the natural logarithm of 2, and k_T the total removal rate from a medium. Given a reaction rate for the dominant removal mechanism, it is possible to estimate environmental concentrations (and thus dose) using simplified fate models and knowledge of chemical release rates.

Dose is estimated by first identifying the possible routes of contaminant intake by humans. Disposal of waste containing a highly volatile component, for example polyvinyl chloride reactor waste, may cause release of vinyl chloride to the atmosphere and result in exposure via inhalation. Similarly, disposal of a waste containing a highly water-soluble or mobile component such as trichloroethene may result in contamnation of both ground and surface waters. If groundwater contaminants are used as an example, several possible routes of human intake bcan be identified.

- o Direct ingestion through drinking.
- o Inhalation of contaminants that volatise when water is heated (as in a shower) or boiled.
- o Absorption through the skin during washing and bathing.
- o Ingestion through consumption of food derived from plants or animals exposed to groundwater.
- o Absorption through the skin during the handling of soil exposed to groundwater.

If the concentrations of contaminants in each of these media (water, food, soil, air) are known, and the extent and frequency of human contact with and intake of these media are known, then the average human dose of each of the contaminants can be estimated. In most cases, dose estimation is relatively uncertain because of uncertainties in knowing the concentrations of contaminants and the magnitude and frequency of human contact with and intake of various media. It has become common practice to adopt certain average values for contact and intake via certain media in order to make estimates of dose (e.g. 2 litres of water consumption per day for adults).

An additional factor influencing dose is absorption. Substances that are ingested must pass through the gastrointestinal wall, and substances coming into contact with the skin or lung must pass through these barriers in order to have a toxic effect [1]. Not all substances pass through these barriers at the same rate, so information about absorption rates is needed in order to estimate internal dose. This information is frequently not available, so again it has become the practice to adopt absorption-rate values based on studies of compounds having similar chemical and physical characteristics.

---

1 We note that some substances produce toxicity directly at the point of contact (skin, lung, g.i. tract). Absorption is necessary if effects are to be produced at internal body sites (systemic effects).

An exposure assessment is designed to yield dose estimates for both short-term and long-term exposure (exposure to environmental contaminants is rarely constant over a lifetime, and may cover only a fraction of a lifetime). These does estimates are used to determine the likelihood of acute and chronic toxicity in exposed persons and are applied in the risk characterisation component of risk assessment.

As discussed in the previous section, the fate and transport of chemical wastes through environmental media is not only a function of the physical-chemical properties of the individual chemicals in a waste, but also of the environment through which they move. Exposure to a chemical agent as a result of improper waste disposal is therefore a site-specific issue. There are thousands of disposal sites, each of which may be situated in a different environment and thereby represent a unique exposure to each population. Such considerations, while of great importance in the siting of a landfill and ultimately in determining risk, are not necessarily critical to the development of a hazardous waste ranking methodology and are not discussed further.

Table 3B.1
Environmental Processes

Process	Pathway	Physical-Chemical Properties
Physical Mechanisms:		
Volatilisation/Washout	Surface Water Atmosphere	Primarily the vapour pressure of the compound and its water solubility.
Adsorption/Desorption	Surface Water Particulates	Primarily an adsorption - desorption process, involving the solubility of the chemical in water and the factors influencing its adsorption on the solid phase. Solubility, partition coefficients, and heats of solution become significant in this regard.
Volatilisation/Washout Dry Deposition	Particulates Atmosphere	A complex system concerned with the adsorption of the chemical on the soil surface, its vapour pressure, and also the influence of water as its may affect the movement of the chemical to the soil-air interface.
Bioconcentration	Surface Water Biological Media	The movement of a chemical across a membrane; an absorption process in contrast to the surface adsorbtion.
Chemical Reactions:		
Hydroxyl and Other Raidcal		
Ozonolysis	Atmosphere Surface Water	
Photolysis		Primarily a function of the chemical properties of a compound.
Hydrolysis		
Oxidation/Reduction Biodegradation	Groundwater Surface Water	