4 Ecological Aspects*

Our interest in the ecological aspects of chemical accidents can be divided into two broad categories: the effects on plants and animals themselves; and use of these organisms as indicators of exposure and biological damage that may be helpful for human health considerations.

The routes of dispersal of chemicals following accidental release have been described earlier in this Joint Report (Chapter 2). All that needs to be mentioned here is that accidents, which involve chemicals reaching lakes and rivers, are the ones involving the most serious ecological consequences. In general, there is little correlation between chemical accidents that cause heavy human mortality and those causing major ecological damage.

4.1 EXPOSURE

A knowledge of exposure is basic to any toxicological assessment. Without adequate exposure data, it is virtually impossible to make a reliable estimate of risk caused by the presence of chemicals. In a previous volume (SGOMSEC 2, Vouk et al., 1985) the following definition of exposure was adopted:

The exposure to a given pollutant is a measure of the contact between the pollutant and the outer or inner (e.g. alveolar surface or gut) surface of the human body. It is usually expressed in terms of concentrations of the pollutant in the medium (e.g. ambient air and food) interfacing with the body surfaces. Once absorbed through the body surfaces, the pollutant gives rise to doses in various organs or tissues. Doses are measured in terms of concentrations in the tissues. Records of exposure and dose should include an indication of the time and frequency at which an individual is subjected to them.

4.1.1 Terrestrial Organisms

The basic routes of exposure for terrestrial animals are similar to those of humans, viz. the epithelial lining of the lungs, the digestive tract and the skin. However, while inhalation and dermal routes will still be the initial routes of exposure, it is much more difficult to control subsequent input of the chemical via food and drinking water. It is likely that the death of small domestic animals

* This chapter was prepared by a working group chaired by P. Bourdeau. The members were D.B. Peakall, V. Landa, D.K. Biswas, V. Agnihothrudu and T. Chandini.
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(largely chickens and rabbits) at Seveso was the result of feeding on contaminated food (Fanelli et al., 1980). Hence, toxicity occurred via the oral route, rather than from delayed effects from inhalation from the initial cloud. For human beings, it is usually possible to provide clean food and drinking water after an accident; for wildlife, this is generally impossible.

For terrestrial plants, atmospheric contaminants will enter mostly through the stomata on the leaf surface, whereas soil pollutants will penetrate via the roots and other underground organs.

4.1.2 Aquatic Organisms

For fish, the most important routes of uptake are via the gills and digestive tract. For invertebrates, the whole body surface can be involved. The relative importance of direct uptake from the water and uptake from food will depend on the characteristics of the chemical. If the chemical is persistent, and particularly if it is also lipophilic, then food chain effects can be expected to predominate. For aquatic plants, chemicals may be taken up by the stems and leaves.

4.1.3 Ecosystems

For the ecosystem as a whole, the major consideration is likely to be the total burden of the chemical to which the system is exposed. Considering the environment as a whole, the amount of most chemicals involved in most chemical accidents is small compared to inputs from other sources. However, contamination may be high locally and the possibility of widespread contamination has been clearly demonstrated by the recent accidents on the Rhine.

There are exceptions to this generalization. For example, the annual US spillage of PCBs is \(1 \times 10^5\) kg (US EPA, 1985) which can be compared to the calculated annual input the Great Lakes of \(6 \times 10^4\) kg (Eisenreich et al., 1981).

Once chemicals have reached the soil or sediments, they can remain there for prolonged periods of time. This can lead to exposure of the micro- and macro-flora and fauna of the soil and sediments.

4.1.4 Problems in Estimating Exposure and Dose for Non-Human Targets

As for humans, the nature and extent of exposure immediately following the accident may be difficult to assess. The identification of the chemicals released or produced shortly after release and their quantification are of prime importance for determining counter measures. In addition, for non-human targets and the ecosystem, it is necessary to trace the pathways and chemical transformations of the released compounds as they are transferred in the environ-
Table 4.1 Biological markers for exposure assessment of non-human targets

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Marker</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airborne pollutants</td>
<td>Visible lesions</td>
<td>Higher plants are sensitive</td>
</tr>
<tr>
<td>( \text{O}_3, \text{NO}_x, \text{F} )</td>
<td></td>
<td>Difficult to establish</td>
</tr>
<tr>
<td>Polynuclear aromatics</td>
<td>Variable lesions</td>
<td>Tumours in fish</td>
</tr>
<tr>
<td>Smoke</td>
<td>Variable lesions</td>
<td>Semi-quantitative</td>
</tr>
<tr>
<td>Dioxins</td>
<td>Genetic markers</td>
<td>Birds with crossed beak</td>
</tr>
<tr>
<td>Smoke</td>
<td>Genetic markers</td>
<td>Melanism in moth</td>
</tr>
<tr>
<td>Mutagenic compounds</td>
<td>Genetic markers</td>
<td>\textit{Drosophila} mosaic test</td>
</tr>
<tr>
<td>Microbiological insecticides</td>
<td>Immunological</td>
<td>Insect immunology affected</td>
</tr>
<tr>
<td>Pesticides/metabolites</td>
<td>Cytological</td>
<td>Mitochondrial swelling</td>
</tr>
<tr>
<td>Polynuclear aromatics</td>
<td>Acetylcholine</td>
<td>Can be used over a wide range of taxa</td>
</tr>
<tr>
<td>Organophosphates</td>
<td>Acetylcholine</td>
<td>Non-specific. Low</td>
</tr>
<tr>
<td>Carbamates</td>
<td>Acetylcholine</td>
<td>in insects</td>
</tr>
<tr>
<td>Induction of hepatic mixed function oxygenase</td>
<td></td>
<td></td>
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<td></td>
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</tbody>
</table>

Source: Modified from SGOMSEC 5 (To be published).

ment and affected by biotic and abiotic agents. They may give rise to more toxic or to less dangerous chemicals or be immobilized in certain environmental compartments possibly to be released later on. The required information may be available for many chemicals from pollutant-related studies and should be in a readily usable form but this is not always the case – as exemplified by 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) for Seveso and methyl isocyanate (MIC) for Bhopal. In these cases, because the compound involved was not normally found in emissions or effluents, the capability to make routine measurements was not available. There was no database or environmental fate. These problems apply particularly to chemical intermediates.

Biological markers which could be used for exposure assessment of various plants and animals are presented in Table 4.1.

### 4.2 ECOLOGICAL EFFECTS

Wildlife conservation is based more on the preservation of populations and communities than on concerns for the individual. Exceptions to these are domestic animals and the management of endangered species for which the survival and health of the individual are of concern.
4.2.1 Domestic Animals

In many ways, the considerations involved in dealing with domestic animals are similar to those of human beings. The concern for domestic animals, ranging from prize-cattle to livestock on which life itself may depend, is largely at the individual level. Since most domestic animals are mammals, the toxicological database against which the assessment is made is similar to that used for human beings. The possibility of evacuation of domestic animals is much higher than for wild animals and again has more in common with evacuation of humans than it does with wildlife.

4.2.2 Wildlife Concerns

While exposure analysis is similar for human and non-human targets, the same is not true for the necessary toxicological data to evaluate the effect of the exposure. The lack of comprehensive comparative toxicological data is a major difficulty. Obviously complete sets of comparative toxicological data are impossible; generally only a scattering of data on mammals and birds, fish and invertebrates are available. International registries are beginning to be available, such as UNEP International Registry of Potentially Toxic Chemicals, which can be used to evaluate the impact of chemical accidents. (See Appendix in Part A of this volume for additional resource documents.)

4.2.3 Endangered Species

While chemical accidents do not rate high in the list of threats to endangered species, they can be important in specific cases. Contingency plans have been developed in the US Fish and Wildlife Service Whooping Crane Recovery Plan to handle the possibility of chemical accidents threatening this species. The entire population of this species winters on the coast of Texas close to the Gulf Intracoastal Waterway. It has been proposed that a small section of this waterway be moved away from the crane’s wintering ground. So far, this recommendation has not been acted on, but contingency plans to evacuate cranes by luring with bait or hazing with helicopters, have been developed as part of the Whooping Crane Recovery Plan.

There is increasing concern over the loss of species diversity on a global basis. National and international lists of endangered species exist and are being expanded and updated. A major effort to compile information on threatened species is run by the International Union for Conservation of Nature and Natural Resources. It publishes, with the aid of experts from around the world, a series of data books on endangered, rare and vulnerable species. It is suggested that chemical accidents are considered as one potential threat to these species. Comparison of the range of these species with chemical plants,
storage facilities and major transportation routes should enable a preliminary assessment of hazard to be made. If this hazard appears to be serious, contingency plans should be developed. In this way, chemical accidents could be included in the mainstream of concerns of loss of species diversity.

4.2.4 Plants

Natural vegetation and agricultural plants may be contaminated directly through dry or wet deposition of chemicals. Spray irrigation with contaminated water is another possible route for farm crops.

In several accidents involving atmospheric dispersal, observations were made of direct effects on terrestrial plants such as foliage lesions, leaf wilting and abscission, reduced flowering and mortality. Vertical and horizontal gradients of the intensity of these effects were recorded, probably related to exposure.

If the released chemical is highly toxic to animals and man, e.g. TCDD, and present in relatively low concentrations, the concern with plant and soil contamination is motivated by the possible transfer of the toxicant to man and to animals through the food chain (see Section 4.2.5). Even though the plants are apparently not affected, the crops must be destroyed with subsequent economic loss and the soil may have to be decontaminated or the topsoil removed altogether. This may prove to be extremely costly and destructive of the local ecology and landscape.

Effects on aquatic plants are less well known from direct observations following accidents. They may be predicted if the chemicals involved, such as herbicides, have been investigated previously for other reasons. Obviously, such parameters as sorption on sediments and suspended particulates, degradability in water, seasonal effects, etc., are of paramount importance in determining the extent of damage to phytoplankton and macrophytes.

4.2.5 Food Chain Contamination

In most ecosystems, there are a considerable number of interlocking food chains or webs. In order to know the exposure of any specific part of the ecosystem, it is necessary to measure the movement of the chemical through the food chain. In the case of stable, lipophilic compounds, biological magnification occurs so that organisms in high trophic levels, including man, are at risk. Spills of compounds of this type such as PCBs and TCDD, provide the opportunity for detailed investigations to be made that would otherwise not be possible. For example, a good deal of information was obtained on the movement of TCDD from soil to plants, and the relationship between levels in plants and those in animals from investigations of the Seveso accident. In other cases where the chemical is capable of degradation, such as polynuclear
aromatic hydrocarbons, the levels may be greatest at low or intermediate trophic levels. Since many organisms, both plants and animals, are used as human food, a detailed knowledge of food chain contamination is needed to assess human exposure. Although specifically excluded from detailed consideration in this volume, the widespread contamination of food chains such as lichen-reindeer following the accident at Chernobyl illustrates the importance of food chain studies.

4.2.6 Plants and Animals as Indicators

So far, considerations of wildlife have focused on the effects of chemicals on the health of wildlife. Wildlife are also widely used as bio-indicators of problems of concern to human health. Studies on small mammals have been carried out in the vicinity of toxic waste dumps in order to assess the possible impact on humans living near such sites. Studies on fish and fish-eating birds have been carried out to assess water quality of large bodies of water. These approaches could be used to determine the safety for re-entry into areas contaminated by chemical accidents in the case of persistent chemicals.

Damage to plants can be used as an index to their exposure to the chemical and this can be related to human health concerns. Experimental studies on ammonia and chlorine have shown that damage to leaf structure can be related to the concentration of these gases (Griffiths and Lydiard, 1984). In Bhopal, vegetation studies (scorching and shedding of leaves, damage to flowering plants) have been used to map the degree of damage due to exposure from methyl isocyanate. Although dose–response relationships are fairly well established for foliar lesions for a few chemicals (i.e. NH₃ and Cl₂), they have not been established for many of the chemicals that might be released. In both this incident and Seveso, mortality was observed for a number of terrestrial animals. Autopsies of such animals can be used to aid treatment of human victims. Long-term studies on animals exposed at Bhopal have been undertaken. The changes observed (e.g. collagen alterations in turtles; skeletal effects in birds, and chromosomal aberrations in a variety of species) could be of importance to alert medical authorities to problems that could occur in human beings.

4.2.7 Ecosystem Effects

Changes recorded in domestic animals and endangered species are considered at the individual level. Ecological damage as a result of chemical stress such as adverse effects on the reproductive potential of the species could result in reductions in population dominance and community structure. In addition, mutagenic effects may result in a natural selection towards specific genetic strains.
Such effects could bring about changes not only in the community structure (such as prey–predator interactions, competition, vulnerability to diseases) but also in the functioning of the ecosystem in terms of productivity and nutrient cycling.

Except for oil spills, few data are available in the published literature on the effects of major chemical accidents at the ecosystem level. The recent accident at Basle, which contaminated massively the River Rhine, provides an opportunity for a detailed ecosystem investigation of its consequences. It is anticipated that some results will be forthcoming while this SGOMSEC report is being prepared for publication (see Chapter 12).

It is recommended that any study of the effects of chemical accidents should include investigation of their impact on the affected ecosystem be it terrestrial or aquatic.

4.3 CONCLUSIONS AND RECOMMENDATIONS

4.3.1 Conclusions

1. Major chemical accidents may have important and long-lasting effect on non-human living targets as well as on whole ecosystems. While accidental releases of chemicals in the atmosphere usually have a greater impact on human populations, discharges into water bodies generally affect to a greater extent the non-human biocenoses. Accidents during transport are more likely to have ecological effects than those in production and storage.

2. Of particular importance for the assessment of the ecological consequences of a chemical accident is the understanding of the pathways and transformation of the released chemicals in the environment.

3. Effects on living targets other than man concern domestic animals (mortality, sterility, reduced milk and meat production, teratology, mutations), plants (mortality, loss of foliage, growth reduction, reduction in the viability of seeds), wildlife, especially with regard to endangered species with limited geographical range. Large differences in sensitivity may be expected between species. Whole ecosystems may be affected for an extended period of time, especially rivers and lakes.

4. Effects on plants and animals may serve as indicators of both the levels of contamination reached in the environment and of the effects to be expected in man (e.g. collagen in turtle).

5. Plants and animals entering human food chains may act as vectors to man of the released chemicals or their transformation products, hence the need for monitoring their levels of contamination.
4.3.2 Recommendations

1. Accident preparedness may include the following as far as ecological impacts are concerned:
   - plotting of rare species;
   - identification of sensitive populations and ecosystems, prior to making decisions on siting of production and storage facilities and on routing of chemicals;
   - availability of information on transport and transformation of chemicals in the environment and on their ecotoxicity.

2. Post-accident management: the following may be recommended:
   - identification of the chemicals involved;
   - measurements of concentrations of released chemicals and their transformation products in air, water, soil, plants, animals;
   - recording of gross effects on plants and animals;
   - delineation of affected area and its subdivision in zones of different degree of contamination based on the above-mentioned observations;
   - impose a ban, if warranted, on the consumption of plant and animal products;
   - soil decontamination, or topsoil removal;
   - if applicable, protective measures for populations of endangered species;
   - evacuation of domestic animals;
   - autopsies of affected animals to provide indication for treatment of human beings;
   - organization, as soon as possible, of the monitoring of the basic data to assess impact on the dominant species and those of high indicator value.

REFERENCES


