Methods for Assessing and Reducing Injury from Chemical Accidents
Edited by Philippe Bourdeau and Gareth Green

12 Ecotoxicological Considerations of Chemical Accidents

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> One of five billion individuals of one
> of several million species on a lesser
> plant revolving around a minor star.
> Author unknown

12.1 INTRODUCTION

Although as scientists we recognize that we comprise one of several million species, it is difficult for most of us to put ourselves in such a universal perspective. The primary concern that is expressed when any major accident occurs is its effect on human beings.

To date, the only accidents for which environmental consequences have been studied in detail are oil spills. These are specifically excluded from this volume because of the specialized nature of this type of accident and because of the extensive literature that is available (NAS, 1985). Information on the environmental consequences of most accidents involving other industrial chemicals is limited. A report (US EPA, 1985) states that the environmental consequences of 93% of accidents reported in the United States between 1981 and 1985 were listed as unknown.

Wildlife conservation is more concerned with the preservation of populations and communities than with saving the individual. Only in cases where the management of endangered species is involved do the survival and well-being of the individual become important. Chemical plants are not normally located near habitats important for wildlife. In the EPA report already referred to, three-quarters of the accidents listed were in-plant occurrences.

Furthermore, there is often no relationship between accidents that have significant impact on human health and those with major environmental consequences. For example, the ecological effects of the catastrophic accident at Bhopal were minimal, whereas no human casualties were reported on the accidents on the Rhine in November 1986 which devastated aquatic life over 200 km of the river.

Those responsible for wildlife management have generally treated chemical accidents as a topic of lesser priority than other pressures on wildlife populations. For this reason, methods for dealing with chemical accidents need to be considered as part of the global ecotoxicological picture rather than in isolation. It is the purpose of this chapter to demonstrate that many of the data needed to manage chemical accidents are not only available from wildlife toxicological studies, but are also an essential part of wildlife conservation in general.

12.2 DISPERSAL OF RELEASED CHEMICALS

Models used to calculate or estimate the movement of chemicals will be similar to those used for human considerations (McQuaid, this volume, Chapter 11), but the actions that can be taken for wildlife can differ; these are discussed briefly below.

12.2.1 Gaseous Compounds Released Directly into the Atmosphere

The time-frame of events of this type is likely to be very short – chlorine release at Mississauga, Canada, in 1979 for example – and it is unlikely that any response to round up and evacuate wildlife could be made.

12.2.2 Other Direct Releases into the Atmosphere

This would include the spilling of volatile liquids, and explosive releases, including fires at plants or storage areas. Release may be over a longer period of time than in Section 12.2.1 giving a greater chance of evacuation.

12.2.3 Release into Soil, Surface or Ground Water

From a wildlife point of view, this is likely to be the type of accident for which measures to limit damage could be undertaken. Containment, so as to prevent the chemical agent from reaching the ground or surface water, is the most important measure.

12.3 EXPOSURE ANALYSIS

In general, exposure analysis, especially the short-term exposure analysis as used for accidents, is the same for human and non-human targets. Levels in air, water and soils are all needed for calculations of the risk to both humans and non-humans. Only in the case of persistent chemicals do food chain considerations become important. Polychlorinated biphenyls (PCBs) are the most frequently reported substance (23%) in chemical accidents in the United States (US EPA, 1985) due, at least in part, to the low reporting limit (10 lb) whereas the next most frequently reported chemical, sulphuric acid (6.5%), has a reporting limit of 1000 lb. The total amount of PCBs involved in chemical accidents in the United States during the period 1981 to 1985 is given as 1.2 million lb or approx. 100 000 kg/yr. PCBs were also the most frequently reported chemical spilled in Canada over the period 1972 to 1980, although the amount was only about one-hundredth of that reported for the United States (Fingas, 1982). The total amount of PCBs involved in spills in North America can be compared to the calculated annual input into the Great Lakes of North America of 60 000 kg/yr (Eisenreich *et al.*, 1981). Thus spillage of PCBs is a significant environmental input of these materials.

In contrast to PCBs the amount of SO_2 spilled in the United States (80 000 kg/yr) is trivial compared to that of emissions which are estimated at 2×10^9 kg/yr (Shannon and Volder, 1982).

In the case of large-scale releases of persistent chemicals such as PCBs and tetrachlorodioxins (TCDD), despite attempts to clean up as much material as possible, food chain effects can be expected. These are likely to be more severe for natural top predators than for man, since the former has no ability to rely on food brought in from outside the area of contamination.

12.4 TOXICOLOGY

While exposure analysis is similar for humans and non-humans the same is not true for toxicological data. The lack of availability of comprehensive comparative toxicological data is a major difficulty in all aspects of wildlife toxicology. Obviously complete sets of comparative toxicological data are impossible. The theoretical number of interactions between single chemicals and single species is of the order 10^{13} to 10^{14} and even a modest database for the International Registry of Potential Toxic Compounds (IRPTC) working list of 600 chemicals would be difficult to obtain.

The comparative toxicology available for two compounds of environmental interest [tetrachlorodioxin (TCDD) and carbofuran], taken from a recent IRPTC print-out, is given in Table 12.1. The value of such a computerized database that can be rapidly generated is great in accident situations. The amount of non-mammalian data that is available on TCDD is remarkably small considering the degree of concern that this chemical has generated.

Another benefit of an international registry of toxicological data is to avoid duplication of testing, obviously important from both cost and ethical considerations. International agreement on protocols used to generate data is important in this context. The data required under the European Economic Community Sixth Amendment and under the Minimum Pre-Market Data of the OECD represent an important start in this direction. Although the number of species tested is very limited, databases of this kind have the advantage of presenting strictly comparable data for a large number of chemicals.

Table 12.1 Acute toxicological data taken from IRPTC

Species	TCDD LD_{50}*	Carbofuran
Mammals		
Guinea pig, male	0.6 µg/kg	43 mg/m^3 (Inh)
female	2.1 µg/kg	
Rat, male	22 µg/kg	
		5.3 µg/kg,
		120 µg/kg (Dermal)
female	45 µg/kg	
Rabbit	115 µg/kg	885 mg/kg (Dermal)
Mouse		2 mg/kg
Human		11 mg/kg
Birds		
Chicken	25–50 µg/kg	
Fulvous tree-duck		240 µg/kg
Mallard		370–628 µg/kg
Bobwhite quail		5040, 10250 µg/kg
Pheasant		573, 4150, 9600 µg/kg
Fish		LD_{50} (24 hours)
Salmon	Death within 27d at 100 ppt	
Brown trout		355–840 µγ/1
Steelhead trout		1020 µg/1
Lake trout		164 µg/1
Channel catfish		2000 µg/1
Bluegill		80 µg/1**
Yellow perch		147 µg/1**
Mosquito fish		300 µg/1**
Other organisms		
Model ecosystem (clam, frog, daphnia, plants)		Death of most organisms 1.12 kg/ha
Pink shrimp		16.8 kg/ha***
Honeybee		0.16 µg/insect
Earthworm		1300–12 200 µg/kg

* oral unless stated ** LC_{50} (96 hours) ***LC_{70} (24 hours)

Source: IRPTC (1986).

A fundamental question is the degree of extrapolation that is reasonable. For avian species a recent analysis of published data on specific groups of pesticides (Mineau and Peakall, personal communication) indicates that there is little phylogenetic relationship of LD_{50} data within the order Aves. Thus, unless the exact target species can be studied, there is little point in worrying about which test species is used. This suggests that in building up a comparative toxicological database one should concentrate on covering as wide a variety of orders as possible rather than on widespread testing within an order. The safety factor needed for oral LD_{50} values within the order Aves has been examined (Peakall and Tucker, 1985) and it was found that only 6% of the values fell outside two orders of magnitude.

The mammalian TCDD LD_{50} data show a wide range, two–three orders of magnitude. Although the Seveso experience suggests that man is one of the less sensitive mammalian species to this chemical (Coulston and Pocchiari, 1983), it should not be assumed that this will be true for other chemicals. Sensitivity rankings among species do not show marked consistencies.

The carbofuran data on fish (Table 12.1) show an inter-species variation of twentyfold. While considerably smaller than that found for the TCDD mammalian data, it is still considerable. Nevertheless, even this variation is small compared to the uncertainties in the values obtained from exposure analysis.

12.5 SITE OF ACCIDENTS

Ecological concerns are more likely to focus on transportation than in-plant accidents. Storage facilities are likely to be closer to wildlife areas than factories or processing plants.

A series of chemical accidents occurred on the Rhine in late 1986 (MacKenzie, 1986) and several more were reported from Eastern Europe at the same time (Walgate and Rich, 1986). Chemical problems are nothing new on the Rhine. A hundred and sixty years ago Coleridge wrote:

> I counted two and seventy stenches,
> All well defined, and several stinks!
> Ye Nymphs that reign o'er sewers and sinks,
> The river Rhine, it is well known,
> Doth wash your city of Cologne;
> But tell me, Nymphs, what power divine
> Shall henceforth wash the river Rhine?

The most serious of these accidents on the Rhine, from a wildlife perspective, was at the Sandoz chemical plant at Basle which involved some 1350 metric tonnes of agrochemicals (including insecticides and fungicides), but there was a total of ten accidents reported in November 1987 on the Rhine (Layman, 1987) including the loss of 400 kg of atrazin from Ciba-Geigy and 200 kg of 2,4-D from BASF.

A warehouse at Sandoz caught fire and in the course of extinguishing the blaze several hundred thousand litres of water drained into the Rhine. The warehouse contained 860 000 kg of organophosphate insecticides, 73 000 kg of nitrocresol herbicide and 11 000 kg of organic mercury compounds (Sandoz Press Conference release). Although it is not known how much of the river suffered severely over a length of 250 km, the most obvious effect was the hundreds of thousands of fish killed (Deininger, 1987). It is claimed that the microbiota remained sufficiently intact to regenerate, but it is likely to be years before the Rhine recovers completely. Whether the European Commission is more effective in preventing such occurrences than Coleridge's Nymphs remains to be seen.

12.6 SPECIES AT RISK AND WILDLIFE AS INDICATORS

The reasons for undertaking wildlife toxicological studies can be divided into two broad categories: first, concern for health of wildlife, and second, as early indicators of danger, especially for human beings. These objectives are not necessarily mutually exclusive and in this section both aspects are examined.

12.6.1 Domestic Animals

Domestic animals are a special case which are better treated as a subset of human health than in broad ecotoxicological terms. The reasons for this are:

1. Most domestic animals of concern are mammals and the toxicological database against which the assessment is made is the same mammalian toxicological database used to assess risk to human beings.
2. With domesticated animals – whether it be expensive race-horses, livestock on which human life can depend, or domestic pets – the concern is, to a great extent, for the individual rather than the population.
3. The possibility of evacuation is much higher than for wild animals and has more in common with evacuation of human beings than of wildlife.
4. Autopsies and examination of sick domestic animals can be a valuable clue to the treatment of human beings. At Seveso thousands of small domestic animals died (largely rabbits and chickens) within the first few weeks of the accident. Autopsies showed various pathological signs and rabbit liver levels corresponded fairly well to the degree of soil contamination (Fanelli *et al.*, 1980) and thus animal mortality was a useful biological indicator of damage.

Wildlife could also be used, but are likely to be much less readily available. Furthermore, exposure of man and wildlife is less likely to be as similar as between man and domestic animals, so the degree of extrapolation of toxicological data needed is reduced.

12.6.2 Endangered Species Occupying Limited Geographical Area

The possibility that chemical accidents could be a serious hazard to the entire population of Whooping Crane has been considered in the US Fish and

Wildlife Service Whooping Crane Recovery Plan. While so far no injuries or losses of cranes attributable to accidents have been documented, there is a definite potential. Numerous oil and gas wells and connecting pipelines are located near the crane's habitat. Barges carry toxic chemicals along the Gulf Intercoastal Waterway daily and a spill could poison the cranes and/or their food supply. The recommendation of this report is to move a portion of the waterway eastward away from the crane's wintering grounds. So far this recommendation has not been acted on. As a contingency plan it is recommended that if a significant spill or leak of dangerous material occurs the cranes should be lured away using grain bait and/or burning of upland areas which then become more attractive to cranes. Under extreme conditions cranes could be hazed away from the danger area, probably using helicopters. The report continues that equipment to contain and remove oil should be available for quick deployment. To my knowledge this represents the first time that detailed contingency plans have been developed to save a wildlife species from the consequences of a chemical accident.

At a meeting sponsored by the Royal Swedish Academy of Sciences to examine environmental research and management priorities for the 1980s (Munro, 1983), the loss of species diversity was identified as one of the ten top research priorities. In the report, Global 2000, prepared by the US Council on Environmental Quality (Barney, 1980) it is stated that the loss of hundreds of thousands of species can be expected by the year 2000. Although the scientific basis for these predictions is weak (Simon, 1986) it remains a source of serious concern. The key is detailed knowledge of the distribution of rare species in areas of risk. These databases are needed to avoid loss of species diversity from a wide variety of pressures, including chemical accidents.

A major effort to compile information on threatened species has been carried out by the International Union for Conservation of Nature and Natural Resources (IUCN). A series of IUCN Red Data books on endangered, vulnerable and rare species have been published by experts from throughout the world. For example the *IUCN Plant Red Data Book* (Lucas and Synge, 1978) gives information on 250 plants threatened or potentially threatened on a world scale. The threats faced by these species are broken down into 22 categories. While these do not include chemical accidents, road building comes the closest, since many accidents occur during transportation. For example, the small perennial herb, *Astragalus beatleyae*, is restricted to a small area of Nevada which is bisected with roads. A major accident of a phytotoxic chemical in this area could have a major impact on the survival of the species. The limitation of the IUCN approach, from the viewpoint of the effect of chemical accidents, is the lack of rapidly accessible data. In the United States there is formal legislation protecting endangered and threatened species (US Title 50, Part 17).

12.6.3 General Wildlife Concerns

Beyond the preservation of endangered species there is the general interest in preserving wildlife and wildlife habitat. Interest tends to focus on populations of locally rare species and habitats that are especially limited in area. Concerns over wildlife tend to be phylogenetic; it is much easier to get support for the preservation of a mammal or bird than an insect.

As far as general wildlife health is concerned, chemical accidents should be considered as a potential threat. With the exception of oil spills chemical accidents have not been shown to have serious influences on wildlife populations.

12.6.4 Wildlife as Indicators

The use of domestic animals as indicators has already been mentioned (Section 12.6.1). Wildlife could be used but, to date, little use seems to have been made of them.

Griffiths and Lydiard (1984) examined the use of damage to vegetation as a means of determining exposures to ammonia and chlorine. These workers considered visual damage (incidence in excess of 75%), internal content of ammonium or chloride ions and rates of nitrification and ammonification of soils. Their tests showed clear-cut results only at rather high concentrations, i.e. above 100 ppm. Other tests they investigated – glutamine synthetase activity, chlorophyll content and weight changes – were not considered sufficiently reliable to be useful.

A good deal of work has been carried out on the effects of airborne pollutants, especially ozone, and the oxides of nitrogen and sulphur on plants (Hindawi, 1970; Malhotra and Blauel, 1980). This work has been concerned with chronic effects of relatively low levels, but some of the findings may be of value as potential methods of assessing the concentrations of chemicals following spills.

12.7 LONG-TERM ISSUES

Studies of the movement of persistent materials through the food chain and their subsequent effects at various trophic levels may well be of fundamental interest especially if the data can be linked to a reasonably accurately known amount of chemical. Such studies present an opportunity that would otherwise only be available by deliberate release which may well be considered undesirable or unethical. It is possible to study the impact of a single chemical since the material spilled is likely to be at a much higher level than background contamination. Ecotoxicological studies in highly polluted areas such as the Great Lakes of North America and the Baltic are bedevilled by the presence of a large number of contaminants. Thus it is often difficult or impossible to assign any particular effect to any particular compound.

If ecotoxicological studies are to be undertaken it is important to mark or tag individuals of any species that is capable of moving into or out of the area of contamination. Methods to mark wildlife have been worked out for most orders of animals in connection with other types of biological studies. In some cases, especially for birds, well-organized national programmes are in existence. Radio tracking devices are available for use on a wide range of organisms.

Samples will need to be collected at different trophic levels, both as near to time zero as possible and subsequently. Adequate and accurate labelling is essential. Protocols for such collections are likely to be available from other ecotoxicological investigations. Tissue banks are available in many countries and such depositories can be used not only to preserve specimens, but also as a likely source of information on how samples should be collected and preserved.

12.8 CONCLUSIONS AND RECOMMENDATIONS

The recent disaster on the Rhine has brought to wildlife managers the reality of chemical accidents as a serious problem. Fortunately, in this instance, no loss of human life was involved. The human health implications were limited to contamination of drinking water. In contrast the major chemical disasters in Bhopal and Mexico City did not cause significant loss of wildlife.

1. Chemical accidents should be considered in the assessment of potential threats to endangered species. If assessment indicates the likelihood that chemical accidents could be a serious threat, contingency plans should be developed.
2. Major interdisciplinary programmes are in place for many major waterways, e.g. the St Lawrence River, Baltic, Rhine, etc. These studies should include contingency plans to handle the possibility of major chemical accidents.
3. Greater use should be made of wildlife as indicators of exposure and to assist medical authorities in diagnosis and treatment of victims following major chemical accidents.

In general terms the overall recommendations is to consider chemical accidents as one of the potential threats to wildlife and to use wildlife more extensively as a tool to obtain vital information when chemical accidents occur.

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