CHAPTER 1

General Considerations

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1.1. INTRODUCTION

One of the main differences between classical toxicology and ecotoxicology is that the latter is a four-part subject. Any assessment of the ultimate effect of an environmental pollutant must take into account, in a quantitative way, each of the distinct processes involved (Truhaut, 1975).

First, a substance is released into the environment; the amounts, forms, and sites of such releases must be known if the subsequent behaviour is to be understood.

Second, the substance is transported geographically and into different biota, and perhaps chemically transformed, giving rise to compounds which have quite different environmental behaviour patterns and toxic properties. The nature of such processes is unknown for the majority of environmental contaminants, and the dangers arising from our ignorance of the ultimate fate of certain chemicals have been well documented in recent years.

The third part of the process is the exposure of one or more target organisms. For this to be assessed, one must first identify the nature of the target (man himself, livestock or similar resources, etc.) and the type of exposure that is to be examined.

Fourth, one has to assess the response of the individual organism, population or community to the specified (perhaps transformed) pollutant over the appropriate time scale.

In order for a proper ecotoxicological assessment to be made, this combination of steps must be examined in a quantitative and integrated way. Just as one must try not to allow environmental dangers to go unchecked, it is equally undesirable to impose restrictions on the use of some substance simply because it is 'potentially toxic', for example, if the above combination of processes has not been carefully examined (National Academy of Sciences, 1975).

Because of the requirement for quantitative precision, one might add a fifth facet to the procedure, and that is an estimate of the uncertainty and possible error in our current understanding of the other four. It is evident that our 'best' estimates of the final effect of releasing some substance should be based on our 'best' estimates of the various intervening steps. In the process of making such estimates, a natural by-product is an idea of the uncertainties in the various steps themselves, and the levels of confidence in the understanding of the various processes usually turn out to be quite different (NAS, 1975).

This is important for two reasons. First, any decisions based on an overall process, one or two parts of which are imperfectly understood, ought to incorporate correspondingly large safety factors, whereas if we are confident in predictions the margin for error may be reduced (Holcomb Research Institute, 1976).

The second, and equally important, reason is that we are naturally led to an ordering of priorities for further research. Problems given the highest priority should have to do with either highly uncertain pathways or those which preliminary study indicates involve considerable hazard (Patten, 1971).

The procedures for assessing some of these steps are, of course, just beginning to be developed. Also, the process of combining the conclusions into an overall judgment, including a judgment of the uncertainties involved, exists only in a preliminary form (Patten, 1976). However, some principles are available. It is the purpose of this Section to focus on several of these principles so that their further development may proceed more quickly.

1.2. SOURCES OF POLLUTANTS

There are more than 30,000 chemical substances in use in the world today, and this figure is increasing by 1,000–2,000 per year. Many are produced in quite large amounts; estimates vary and are changing regularly, but the following production figures are probably reasonable (Korte, 1976)

Amount produced (metric tons/year, world-wide)	Number of substances produced in excess of this level
500	1,500
50,000	100
1,000,000	50

It is worthwhile pointing out that these figures, although large, do not in themselves mean that concentrations at toxic levels are to be expected in most areas. Uniformly distributed over all the land area of the earth 500 metric tons amounts to a surface dose of 3.4×10^{-3} mg/m^2. Even if distributed over agricultural areas only, the dose would still be only 1.2×10^{-2} mg/m^2 (about 1.75×10^{-2} oz/acre). What this means is that, in general, concentrations of such substances are negligible; but, since local levels may easily rise to three orders of magnitude above average by natural concentrating factors alone, the potential for ecotoxic effects is very real for a wide range of substances.

An estimated growth rate of the chemical industry of even 2% per year on a world-wide basis, certainly conservative in the opinion of many, will mean more than a *sevenfold* increase in overall use within one hundred years, and concern for the environment must be a prime concern of mankind. It has been said that we have only perhaps two generations in which to change radically our handling of chemical substances in many countries.

It is convenient to begin with the chemicals themselves, and several characteristics of potentially hazardous substances can be set down. The first involves amounts, including amounts manufactured and the releases to the environment, both deliberate and accidental, which can be expected to accompany various use patterns (Freed and Haque, 1975). Such data, it must be admitted, are frequently quite difficult to obtain, since they provide considerable insight into the detailed operation of particular industries. Nonetheless, if we are adequately to assess ecotoxicological danger, a rather complete analysis must first be made of amounts which enter the various pathways, including those not released intentionally into the environment, along with an estimate of probable losses, avoidable and otherwise, from each. Those include mining or otherwise obtaining of raw materials, the production process itself, shipping, including imports and exports as well as transport to place of use, losses during application, and losses during the shipment and reprocessing. Finally, one must assess the release to the environment involved in deliberate application of the substance, or the discarding after use of products containing it (Figure 1.1).

Such an assessment of environmental inputs is a considerable undertaking. Nonetheless, only such an examination can provide reliable information on the total environmental consequences; public attention has frequently been focused on spectacular single or isolated cases of accidental release, while thoughtful examination of all sources may well indicate that widespread losses at much smaller local rates contribute more to the overall release into the biosphere. The petroleum industry is a case in point; the foundering of a tanker carrying tens of thousands of tons of petroleum is a matter of widespread press coverage, while estimates of completely unavoidable losses on an industry-wide basis of upwards of tens of millions of tons per year are deemed acceptable (Korte, 1976). It is to be hoped that such studies of losses associated with overall use patterns will soon be available for a considerable number of chemical substances.

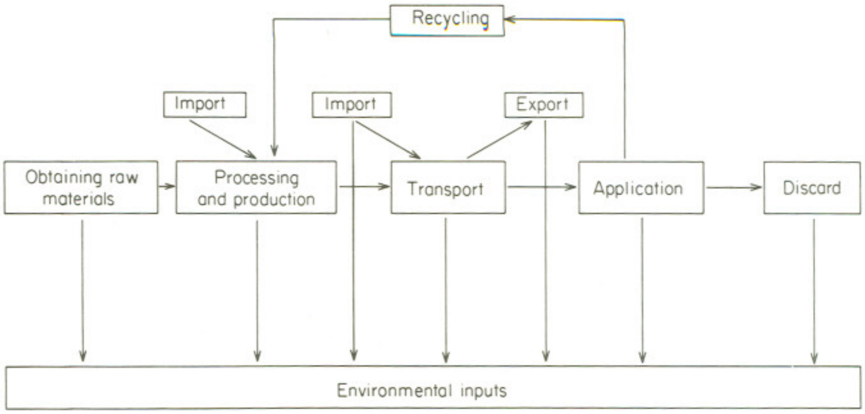

Figure 1.1 Inputs to the environment associated with industrial and domestic use patterns

It is also worthy of note that exposures, to man at least, involved in the production, shipping, and application of various substances have long been studied by workers in occupational health, pharmacology and so forth. Exposure resulting from accidental loss to the environment, or ultimate disposal, is an area less well understood (Goodman, 1974).

1.3. NEED FOR ADVANCE ASSESSMENT

The day is long past when one could introduce a chemical into common use and wait until events provided an accident to assess its effect upon release to the environment. Now, society demands that hazardous – in the sense of ecotoxic – substances be identified before being brought into use.

One may be able to find cases in the literature where accidental spillage of a similar or related substance has occurred and make a reasonable prediction for a new chemical. However, this approach presupposes an increasing supply of such 'accidents' – precisely what society, and regulatory agencies reflecting its wishes, will not permit. And it is not possible or desirable to contrive such an event on a real scale; for many environmentally dangerous substances, the ultimate effect is not expressed for many years, and a real-time experiment cannot be used to decide in advance whether the substance might be too dangerous to be used.

Thus we have an obviously impossible problem, namely that scientists must accurately predict the probability, and the nature, of an event that has never occurred. Furthermore, society is likely to demand improved levels of environmental safety, or at least increased reliability of predictions of ecotoxic effects, as time goes by. To an ever-greater extent, then, scientists will have to make assessments, on which real policy decisions will be based, but which are themselves based solely on extrapolation from a knowledge of the properties of the substance, or from small-scale, short-term experiments. Most important at this stage are the particular principles and experiments to be selected.

1.4. PREDICTING ENVIRONMENTAL BEHAVIOUR

As mentioned above, ecotoxicological assessment of a chemical requires information about its behaviour in the environment and in the receptor. The present discussion deals only with the former.

The essential data on environmental behaviour include those for pathways and rates (van Dobben and Lowe-McConnell, 1975). Some general predictions for these subjects are possible from a knowledge of the chemical and physical properties of a substance and the mechanisms of its reactions and transformations. As more quantitative information on pathways becomes available there is correspondingly less need for research on properties and mechanisms as a basis for prediction.

1.5. PHYSICAL AND CHEMICAL PROPERTIES

There have been several attempts recently to identify those physical and chemical characteristics of a chemical which would make it suspect as an ecotoxic substance in the wide sense or would help to predict its environmental behaviour (Goodman, 1974). These examples, in fact, serve as excellent illustrations of two approaches to the question.

Goodman (1974) concentrates on what might be called functional properties. From the standpoint of environmental behaviour, he identifies (i) persistence in the environment, (ii) environmental mobility, and (iii) failure to form inert compounds, as key properties of ecotoxic substances (in addition to various others such as toxicity, the property of sequestering in lipid or bone, etc., which are perhaps best addressed from the standpoint of toxic effects).

Accepting such characteristics as indicative of potential hazard, we can move to the chemical and physical properties of the substance that would enable a prediction to be made. In such a list would be included:

solubility (in water)
partition coefficient (between solid and liquid, polar and non-polar media)
dissociation constants
formation of chemical complexes
degradation, hydrolysis or photolysis
volatilization
leaching and dissipation characteristics

For an understanding of the behaviour of most chemicals in an ecosystem the properties listed above are the most important. Usually, biological behaviour contributes very little to the large-scale transport or transformation of chemicals and is important mainly for an understanding of routes to, and effects on, receptors.

1.6. MODELS AND MODEL ECOSYSTEMS

If the various characteristics in the above list, of the substance, are well understood, it is possible to predict the overall distribution that should be observed in a typical simplified ecosystem. The most important characteristics that must be understood in an aquatic system, for example, are the partitioning between water and bottom sediment, between water and suspended materials, rates of volatilization and degradation, and availability for uptake by biota. Most of these can be estimated on the basis of the chemical and physical properties.

It might be useful to point out that refining numerical estimates of parameters, once the natures of the dominant mechanisms have been determined, is not a difficult process. Programming of a given model on a digital computer is a familiar business, and the application of such techniques as sensitivity analysis has become routine (Patten, 1976).

This statement unfortunately applies only to simple, quasi-static ecosystems. In more unstable situations, such as would be expected when organic chemicals are exposed to sunlight, or metabolized on a large scale by bacteria, the mechanisms would be more complicated (van Dobben and Lowe-McConnell, 1975).

What is needed, then, is progress in two directions. The first is a refinement of techniques of discussing quantitatively the chemical and physical parameters in the above list, and the second is a way of identifying mechanisms that might be dominant in ecosystems of a slightly different type. The two chapters to follow deal primarily with the second subject area.

1.7. CONCLUSIONS

By way of providing a summary of this section, we may identify the following conclusions:

(1) The technology of predicting environmental behaviour of pollutants has developed substantially in recent years, but needs to be further refined.

(2) Such refinement will be accomplished most effectively by concentrating on overall pathways and movements and general physical and chemical properties, not on detailed chemical or biochemical mechanisms.

(3) A list of those physical and chemical properties most important in predicting environmental behaviour can be compiled.

(4) Predictive mathematical models will be increasingly useful, but more attention must be paid to quantitative assessment of errors and uncertainties of their predictions.

(5) Examination of mathematical models can materially assist in identifying those pathways and mechanisms most in need of further investigation.

1.8. REFERENCES

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