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Hazard Assessment of Chemical Contaminatnts in Soil

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SUMMARY

This report describes methods for assessing hazards to man and other organisms in the environment when they are exposed to soil contaminants resulting from past waste disposal, spills, leaks and local aerial pollution, but not from more diffuse aerial deposition, such as acid rain.

Hazard assessment is based on a comparison of maximum tolerable exposure levels (MTEL) with the estimated or measured environmental exposure levels (EEL). The MTEL is derived from toxicological experiments with experimental species, taking into account an appropriate safety factor.

The potential effect of chemicals on man is estimated from animal dose-response toxicity studies, using oral, dermal and, when appropriate, inhalation exposure routes. Epidemiological studies as well as case studies can be a valuable source of additional information. The potential effects of chemicals on other organisms in the environment are estimated from dose-response toxicity tests on indicator organisms, such as mammalian species, higher plants, soil micro-organisms and earthworms. If necessary, tests can be extended to other organisms, such as birds, fish, Daphnia and bacteria.

In this report particular attention is paid to the assessment of exposure levels. The level and route of exposure of organisms in the environment (including man) depends on the distribution of the chemical between the solid, gaseous and liquid phases. The duration of the exposure depends on the mobility and rate of degradation of the chemical and the contamination characteristics. The partitioning of a chemical between the solid, liquid and gaseous phases can be estimated from the physico-chemical properties of the chemical and soil, whereas degradation rates usually have to be measured. The chemical and soil properties having most influence on exposure are described and methods for their determination are summarised.

A detailed mathematical model, which can be used to estimate total human exposure by oral, inhalation and dermal routes, is presented. Although not

fully validated, it gives an indication of the most important exposure routes and the level of exposure.

A step - wise approach to hazard assessment for man is recommended. The first step is an initial evaluation to establish whether potential exposure exists. If not, no further assessment is required. If there is a potential exposure, a preliminary assessment is carried out by comparing MTEL values with EEL values calculated using the Human Exposure to Soil Pollutants (HESP) model. The HESP model has the advantage that it calculates not only the total exposure of man to soil contaminants, but also calculates the equilibrium concentrations of the contaminants between various environmental compartments. This allows comparison of exposure levels with generally accepted ambient environmental exposure standards, e.g. air-, ground- and surface water quality guideline levels. If the calculated EEL exceeds the MTEL for a particular exposure route then EEL values should be measured. If the measured EEL exceeds the MTEL, a hazard is likely, and a risk assessment should be carried out to estimate the probability of the hazard being realised under local circumstances (this step is beyond the scope of this report).

Hazard assessment for other organisms in the environment should be conducted following the same principles as for man. MTEL values are determined using key indicator organisms, preferably those which are relevant for the contaminated site.

The exposure assessment for man is illustrated using DDT, toluene and zinc as examples. The model calculations suggest that, as expected, for highly volatile compounds the inhalation route is the most important. For water soluble substances which are poorly sorbed by soil, ingestion of residues taken up by crops can be important. For compounds which bioaccumulate, such as DDT, ingestion via meat and dairy products can be an important exposure route. For many compounds inhalation of dust and dermal sorption appear to contribute little to the total exposure.

A. INTRODUCTION

The focus of environmental interest and concern evolved from water and air pollution in the 1950s to the 1970s to soil pollution in the 1980s partly as the result of the discovery of many locations with contaminated soil. Cases like "Love Canal" in the USA in 1976 (Whelan, 1985) and Lekkerkerk in the Netherlands in 1980 (Baas et al., 1984), where houses were built on former chemical dump sites have been widely reported. Causes of local soil contamination include burial of hazardous wastes, spills and leaks of chemicals and fuels and local aerial pollution.

There has been increasing concern about possible effects of contaminated soil on human health and the environment. Making a balanced response to this concern and deciding on remedial measures has been hampered for many years by a lack of objective and systematic methods to establish whether a situation poses an unacceptable hazard to man or the environment.

Recognising the need for reliable methods to judge the hazard for man and environment of a polluted site, ECETOC established a Task Force with the following terms of reference :

- indicate exposure routes for man and other relevant organisms in the environment of chemicals in soil and their relative contribution to total exposure;

- define minimum set of data required for a hazard assessment of chemical contaminants in soil;

- propose a practical system of hazard assessment of chemicals in soil for man and other relevant organisms in the environment.

In the past, much emphasis has been given to toxicological effects of chemicals to man and other organisms in the environment. Tests methods were established by OECD (1981, 1984, 1988). The results of such tests permit the establishment of Maximum Tolerable Exposure Levels (MTELs) using appropriate safety factors.

This report pays particular attention to the assessment of exposure of man to chemical contaminants in soil.

B. BACKGROUND

Soil consists of minerals, organic matter, water, gases and biota. Soil forming processes transform the parent material (e.g. original rock or geological deposit) into soil. Important soil forming processes are dissolution and movement of inorganic and natural organic substances by infiltrating rain and fluctuating groundwater levels. Plants and other biota as well as factors such as flooding, gravity, wind, solar radiation and temperature changes also contribute to soil formation. The organic matter is derived from dead plants and animals.

Soil is teeming with life; 1 hectare of land can support more than a million earthworms and millions of other animals such as mites, centipedes, beetles and ants, along with countless microorganisms. One hectare of soil can contain 1 ton of earthworms and more than 10 tons of microorganisms. Earthworms help maintain a porous soil structure and are an important source of food for some species of wildlife. Microorganisms play an essential role in processes such as nutrient recycling and decomposition of debris. Although soil animals and microorganisms are not readily visible they, like plants, are important environmental organisms.

No completely uncontaminated soils can be found. Through air transport natural and/or man-made contaminants have been deposited in areas at large distances from their emission source. This phenomenon contributes to the background concentration of chemicals in soil. The increasing sensitivity of analytical techniques has enabled detection of chemicals at levels which were earlier undetectable. Detectability, however, is not synonymous with unacceptability. In addition to such diffuse contamination, soils can contain chemicals such as fertilisers, plant protection chemicals, etc. as a result of cultivation practices.

This report does not deal with changes in soil quality caused by more diffuse aerial deposition or cultivation practices, although these cannot be completely neglected because they may contribute to background levels. The soil in relatively uncontaminated areas such as designated nature conservation areas therefore may contain xenobiotic compounds or higher than normal levels of natural elements which are unrelated to local soil pollution (Edelman, 1983). In particular, the natural levels of inorganic elements e.g. heavy metals, vary widely from place to place.

The complexity of the situation as described above calls for a systematic and consistent approach to the judgement of soil pollution situations. Site specific factors, variable background levels and fluctuating and sometimes widely varying environmental conditions (e.g. climate, fauna and flora etc) should always be considered.

This report deals especially with soil contamination in relatively restricted areas resulting from localised sources such as :

- accidental spills;
- leakage from pipelines and storage tanks;
- disposal of effluents via soak away;
- leaching of chemicals from landfills;
- local aerial deposition.

Pollution resulting from such localised sources is characterised by the long term presence of chemical contaminants tending to an equilibrium situation between various environmental compartments. The same approach to hazard assessment may, however, also be applied to situations where sewage sludge containing chemical contaminants is used in cultivation practices. In the latter case the concentration of chemical contaminants introduced into the soil is generally low leading to a local equilibrium in a relatively short time period.

Exposure to the human being may occur where they live near or on a landfill or close to an emission source. Human exposure may also result from the underground spread of contaminants from landfill, from existing industrial sites or from abandoned industrial sites which are reused for e.g. residential areas, playgrounds, or agricultural purposes.

Soils contaminated with chemicals may give rise to exposure of a variety of other living organisms. Attention should also be given to the direct exposure of environmental species (plant or animal).

This report will consider which data are required and how they may be used to assess the hazard of chemicals present in the soil. Emphasis is put on the determination of the exposure levels, especially in relation to man. A step-wise approach is proposed. A first step in the process is an *initial evaluation* to establish whether a potential exposure exists. If a potential exposure may occur the next step is *exposure level estimation* using a computer model (HESP) to calculate potential environmental exposure levels.

Although the same principles can be followed to assess the hazard for other organisms in the environment, this is not worked out in such detail. Only a general scheme is discussed.

The information required to carry out both hazard assessments is described in chapter C. In chapter D the hazard assessment scheme is presented. Chapter E presents a number of examples of assessment of the hazard to man of contaminants in soil. The human exposure assessment model is described in detail in Appendix 3.

The unambiguous use of some key terms is of utmost importance; the definitions of those used in this report are presented in Appendix 1.

C. DATA REQUIRED FOR HAZARD ASSESSMENT

1. *INTRODUCTION*

The many different hazard assessment schemes available are similar in that they require data on the level of exposure of target organisms and the effects of chemicals on these or relevant indicator organisms. Data can be generated in laboratory and field studies.

This chapter indicates the minimum set of data necessary for a hazard assessment. Some tests currently used to provide the required data, but not described elsewhere, are given in Appendix 2.

2. *DATA REQUIRED FOR EXPOSURE ASSESSMENT*

Target organisms can be exposed to chemicals by one or several routes. Ultimately the total exposure concentration and the exposure duration of an organism to a chemical must be known. These depend on the physico-chemical properties of the chemical, the soil properties and the fate of the chemical in the soil. The bioavailability of the chemical to man and/or other living organisms in the environment must also be assessed. Bioavailability is closely related to the concentrations of a chemical in the liquid and gaseous phases; these can be estimated from the total concentration of the chemical present and its partitioning between the solid-liquid-gaseous phases. The degradability of a chemical is also important because this has an influence on the duration of exposure in the case of discontinued input and on the equilibrium concentration in the case of continued input. Degradability may also influence the rate of recovery of wildlife and plants damaged by spillage.

The rates of movement of chemicals within the soil and into the atmosphere and ground water are closely related to the concentrations of these chemicals in the gaseous and liquid phases. The most important mechanisms for movement are diffusion in the gaseous phase, mass transport in the liquid phase or erosion of contaminated solid matter by wind and water.

The exposures of man and of other environmental organisms to contaminants in soil will be different and are discussed separately. Nevertheless, most of the parameters required for human exposure assessment will also be needed to assess the exposure of other environmental organisms.

The model developed to assess human exposure is described in detail in Appendix 3. The model uses a small number of parameters to characterise the chemical contaminant, the soil and the site. These are the "variable parameters" described in the sections 2.1, 2.2 and 2.3. All other, "fixed", parameters used in the model (e.g. relating to housing, behaviour, food consumption, climate) are agreed beforehand and are characteristic for a certain population in a certain region and have been selected conservatively but realistically as shown in Appendix 3.

2.1. Chemicals

To characterise a contaminant the following data are required:

- Molecular Weight.

- Water solubility (S(w) in $mg.l^{-1}$). Solubility in water influences the potential distribution of a chemical in soil.

- Octanol - water partition coefficient (Koc). This gives an indication of the potential of a contaminant to bioaccumulate and sorb to soil organic matter.

- Equilibrium vapour pressure (P in Pa) is the most important property governing the tendency of a compound to volatilise.

- pKa value. The behaviour of weak acids and bases depends on the extent to which they exist as neutral or charged species. The distribution of chemicals in the different soil compartments will be influenced by the pKa value of the chemical and the pH of the soil.

- Diffusion coefficient in air (Da in m^2/h). This presents a measure of the rate of distribution of a compound in air as a result of molecular diffusion.

2.2. Soil

Soil is a mixture of three phases: liquid and gas present in a solid matrix. Soil characteristics depend on the original rock or geological deposit from which it comes and other parameters such as the organisms living in and on it and climatological factors. With time they modify the original material, giving distinct horizons within the profile (see the podzol below). This modification results in a wide variety of soils differing in physical and chemical characteristics (EEC, 1985). Even within one soil type large variations may occur within a short distance. This section deals with the properties affecting the sorption and the movement of chemicals in soils and consequently their biological availability.

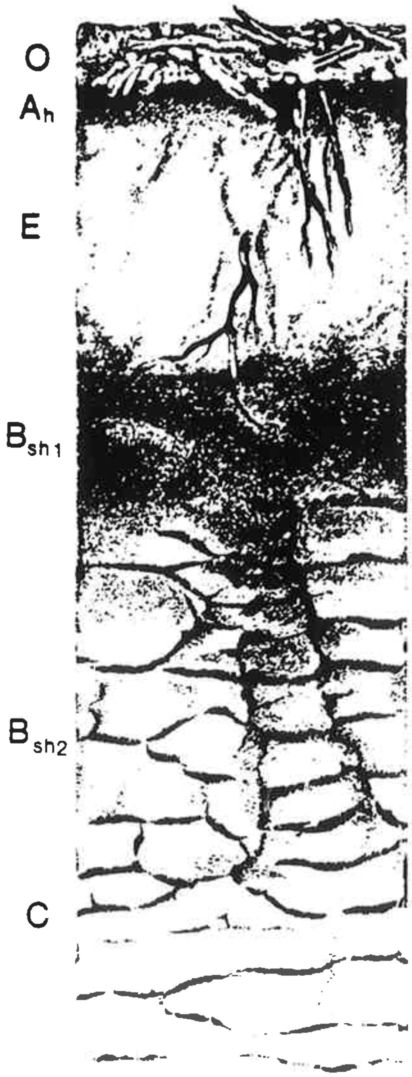
Profile of a podzol

Organic horizon formed from accumulation of organic material deposited on the surface.
Accumulation of humidified organic material intimately associated with mineral fraction.

Loss of humus and sesquioxides.

Illuvial concentration of humus and sesquioxides.

Material from which the soil is presumed to have been formed from.



adapted from Mueckenhausen (1982)

2.2.1. Physical Characteristics of Soils

Physical characteristics of soil, such as porosity and permeability affect the movement of water and vapour and hence the movement of the dissolved chemicals. The particle size distribution has a major effect on porosity (cf. Appendix 3 for definitions of units).

- Porosity (SNp in $m^3.m^{-3}$). Porosity is the volume of pore space in the total volume of soil. The pore space can be occupied by air or water. In the saturated zone of the soil, below the water table, all of the pore space is occupied by the groundwater. In the unsaturated zone, above the water table, water occupies only a fraction of the pore space.

- Air and water content (SNa and SNw in $m^3.m^{-3}$). The air and water content of soil influence the mobility of the contaminant in the soil.

- Density (Sg in $g.m^{-3}$). The density is directly related to porosity. The bulk density of mineral soils normally ranges from 1 to 1.8 $g.cm^{-3}$ (Ahlrichs, 1972; Klute, 1986).

- Permeability (P in $m^2.h^{-1}$). Permeability is defined as the rate at which water passes through a given section of core, under the pressure corresponding to the height of the column of soil used for the determination. It is largely dependent on soil porosity.

- Particle size distribution. Generally, three categories of particle size are distinguished: clay, silt and sand, the last being divided sometimes into fine sand and coarse sand. The EEC (1985) defines the clay, silt and sand size fractions as <2 , 2 to 50 and 50 to 2000 μm equivalent diameter respectively. The particle size distribution determines the surface area of a soil, the finest fractions having the largest specific surface.