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Human exposure modelling for chemical risk assessment: a review of current approaches and research and policy implications

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ABSTRACT

A wide variety of exposure models are currently employed for health risk assessments. Individual models have been developed to meet the chemical exposure assessment needs of Government, industry and academia. These existing exposure models can be broadly categorised according to the following types of exposure source: environmental, dietary, consumer product, occupational, and aggregate and cumulative. Aggregate exposure models consider multiple exposure pathways, while cumulative models consider multiple chemicals. In this paper each of these basic types of exposure model are briefly described, along with any inherent strengths or weaknesses, with the UK as a case study. Examples are given of specific exposure models that are currently used, or that have the potential for future use, and key differences in modelling approaches adopted are discussed.

The use of exposure models is currently fragmentary in nature. Specific organisations with exposure assessment responsibilities tend to use a limited range of models. The modelling techniques adopted in current exposure models have evolved along distinct lines for the various types of source. In fact different organisations may be using different models for very similar exposure assessment situations. This lack of consistency between exposure modelling practices can make understanding the exposure assessment process more complex, can lead to inconsistency between organisations in how critical modelling issues are addressed (e.g. variability and uncertainty), and has the potential to communicate mixed messages to the general public. Further work should be conducted to integrate the various approaches and models, where possible and regulatory remits allow, to get a coherent and consistent exposure modelling process. We recommend the development of an overall framework for exposure and risk assessment with common approaches and methodology, a screening tool for exposure assessment, collection of better input data, probabilistic modelling, validation of model input and output and a closer working relationship between scientists and policy makers and staff from different Government departments. A much increased effort is required is required in the UK to address these issues. The result will be a more robust, transparent, valid and more comparable exposure and risk assessment process.

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1. Introduction

Chemical risk assessment has been defined as 'the evaluation of the potential for adverse health effects in humans from exposures to chemicals' (RATSC, 1999a). The process of chemical risk assessment can be divided into four distinct stages: (1) hazard identification; (2) exposure assessment; (3) dose-response characterisation; (4) risk characterisation (National Research Council, 1989; Risk Assessment and Toxicology Steering Committee (RATSC), 1999a). The exposure assessment stage is crucial and consists of quantifying the level of chemicals to which human populations, population subgroups and individuals are exposed, in terms of magnitude, duration and frequency (RATSC, 1999a). A variety of different approaches exist for quantifying human exposures. Direct methods involve measurements of exposure taken at the point of contact or uptake at the moment it occurs, e.g. personal monitoring and biomonitoring. Indirect methods involve extrapolating exposure estimates from other measurements and existing data, e.g. environmental monitoring, questionnaires, diaries and exposure models (Nieuwenhuijsen, 2003).

An exposure model is 'a logical or empirical construct which allows estimation of individual or population exposure parameters from available input data' (WHO, 2000). Exposure models represent important tools for indirect exposure assessments. They are typically used where direct measurements of exposure or biological monitoring data are not available or where these techniques are not appropriate for the exposure assessment situation. Additionally, there are a number of benefits associated with the use of exposure models for quantifying human exposures:

- They can predict potential exposures for future or hypothetical releases or contact events.
- They allow the utility of existing data to be maximised by combining different types and sources into an analytical structure.
- The degree of complexity adopted by the model can be set according to the needs of the assessment.
- They consider exposures via multiple routes and pathways.
- They reduce the need for resource-intensive monitoring programmes.

Historically risk assessments on common pollutants or commonly used chemicals have been undertaken piecemeal by different UK Government departments and agencies, and elsewhere. However, it is now being recognized that it may be appropriate to consider conducting overall risk assessments for total human exposure (RATSC, 1999a). In order to consider total human exposure it will often prove necessary to evaluate exposures from different types of sources and pathways, which may be the responsibility of different organizations that adopt contrasting approaches to exposure modelling (RATSC, 1999b).

A wide variety of exposure models are currently employed in the UK and elsewhere (Table 1). Individual models have been developed to meet the chemical exposure assessment needs of Government, industry and academia. These existing exposure models can be broadly categorised according to the following types of exposure source: environmental, dietary, consumer product, occupational, and aggregate and cumulative. Aggregate exposure models consider multiple exposure pathways, while cumulative models consider multiple chemicals. In this paper each of these basic types of exposure model are briefly described, along with any inherent strengths or weaknesses. Examples are given of specific exposure models that are currently used, or that have the potential for future use, and key differences in modelling approaches adopted are discussed. Current issues such as data availability, model validity, variability, uncertainty relating to the application of human exposure models for chemical risk assessment are then evaluated in more detail to determine what lessons can be learned and how exposure assessment modelling may be advanced in the future. We will use the United Kingdom as a specific case study, particularly to limit the number of models to be discussed, but the issues discussed apply to many countries. The work will help policy development by identifying gaps in knowledge and methods and suggesting approaches to address these. Clear recommendations are given towards the end of the paper.

2. Examples of exposure models

2.1. *Environmental exposure models*

Environmental exposure models have been developed in an effort to quantify human exposures to chemicals via contact with the surrounding natural environment. A wide range of existing exposure models fall into this category, with individual models tending to focus on human exposures from a limited range of environmental media. For example, the Contaminated Land Exposure Assessment (CLEA) model (Department of the Environment, Food and Rural Affairs (DEFRA), 2002) deals with direct and indirect exposures from contaminated soils; air dispersion models e.g. UKADMS (CERC, 2001) and AERMOD (Perry et al., 1994) can be used to quantify exposure levels in ambient air; contaminant leaching models e.g. ConSim (Golder Associates, 2003) and LandSim (Golder Associates, 2001) can be used to estimate groundwater exposure levels; while pollutant runoff models e.g. SIMCAT (NRA, 1990) allow the quantification of surface water exposures. Regulatory departments and agencies in the UK, such as the DEFRA and the Environment Agency, may utilise environmental exposure models for risk assessment policy and science, both for regulatory and non-regulatory purposes.

Two broad categories of environmental exposure models can be distinguished: (1) environmental concentration models, and (2) human intake models. Environmental concentration models simulate environmental processes in order to generate chemical concentrations in particular media to which humans may come into contact. For example, the ConSim model (Golder Associates, 2003) simulates contaminant transport and degradation processes allowing contaminant concentrations in groundwater to be estimated, UKADMS (CERC, 2001) simulates atmospheric dispersion and degradation processes in order to predict ambient air concentrations. Environmental concentration models are typically sophisti-