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Scenario–model–parameter: a new method of cumulative risk uncertainty analysis

D.J. Moschandreas [a,*], S. Karuchit [b]

[a] *Illinois Institute of Technology, Department of Chemical and Environmental Engineering, Perlstein Hall, Room 233, 10 West 33rd Street, Chicago, IL 60616-3783, USA*

[b] *Suranaree University of Technology, School of Environmental Engineering, 111 University Avenue, Suranaree Subdistrict, Muang District, Nakhon Ratchasima 30000, Thailand*

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Abstract

The recently developed concepts of aggregate risk and cumulative risk rectify two limitations associated with the classical risk assessment paradigm established in the early 1980s. Aggregate exposure denotes the amount of *one* pollutant available at the biological exchange boundaries from multiple routes of exposure. Cumulative risk assessment is defined as an assessment of risk from the accumulation of a common toxic effect from all routes of exposure to *multiple* chemicals sharing a common mechanism of toxicity. Thus, cumulative risk constitutes an improvement over the classical risk paradigm, which treats exposures from multiple routes as independent events associated with each specific route. Risk assessors formulate complex models and identify many realistic scenarios of exposure that enable them to estimate risks from exposures to multiple pollutants and multiple routes. The increase in complexity of the risk assessment process is likely to increase risk uncertainty. Despite evidence that scenario and model uncertainty contribute to the overall uncertainty of cumulative risk estimates, present uncertainty analysis of risk estimates accounts only for parameter uncertainty and excludes model and scenario uncertainties. This paper provides a synopsis of the risk assessment evolution and associated uncertainty analysis methods. This evolution leads to the concept of the scenario–model–parameter (SMP) cumulative risk uncertainty analysis method. The SMP uncertainty analysis is a multiple step procedure that assesses uncertainty associated with the use of judiciously *selected* scenarios and models of exposure and risk. Ultimately, the SMP uncertainty analysis method compares risk uncertainty estimates determined using all three sources of uncertainty with conventional risk uncertainty estimates obtained using only the parameter source. An example of applying the SMP uncertainty analysis to cumulative risk estimates from exposures to two pesticides indicates that inclusion of scenario and model sources increases uncertainty of risk estimates relative to those estimated using only the parameter source. Changes in uncertainty magnitude may affect decisions made by risk managers.

Keywords: Cumulative risk; Aggregate risk; Uncertainty analysis; Variability; Monte Carlo simulation

negligible or ignored (Fayerweather et al., 1999). Failure to account for them could compromise the validity of the outcome and conclusions reached by current methods of estimating risk assessment.

The recently developed concepts of *aggregate* and *cumulative* risks respond to the first and second limitations, respectively (EPA, 1999a, 2000). Risk assessment analysis is evolving as risk assessors formulate models that are more complex, identify many and more realistic scenarios of exposure, and attain new insights that allow the practitioner to estimate risks from exposures to multiple pollutants and multiple routes. This increase in complexity of the risk assessment process is likely to increase risk uncertainties. However, methods to estimate uncertainty associated with risk estimates have remained unchanged. Uncertainty analysis of risk estimates accounts for only parameter uncertainty and excludes model and scenario uncertainties. Risk analysts have not substantiated but assume that model and scenario uncertainties are smaller than parameter uncertainties. In a recent treatment of uncertainty assessment of chemical dose that the authors characterize as "introductory," Hertwich et al. (2000) address all three types of uncertainties. They conclude that scenario and model uncertainty analysis can change dose estimates by several orders of magnitude.

Currently, a specific procedure for a quantitative analysis of scenario or model uncertainty is not available in the literature. A general suggestion regarding analysis of model uncertainty is that risk assessors may use different models to estimate outputs (EPA, 1992a; Hoffman and Hammonds, 1994). The range of outputs can be considered as representing the uncertainty range. A more focused approach that deals specifically with scenario and model uncertainties is known as the distributional approach. This approach has been used in analyses of uncertainty from model structure and alternative assumptions or scenarios (Fayerweather et al., 1999; Evans et al., 1994a,b). The distributional approach divides the risk assessment into a series of decision points called "nodes" that have alternatives. A combination of alternatives from each node constitutes a "tree." Each tree has an assigned probability or "weight" based on expert judgment. This weight is attributed to the risk estimate resulting from each tree. Such results form the final risk distribution. However, the integrity of the final distribution relies heavily on the subjective nature of experts' input. There are also concerns that assigning probabilities to models, i.e., quantifying the possibility of a model to be "correct," is inappropriate (Morgan and Henrion, 1990; Cullen and Frey, 1998). Although the literature does not explicitly refer to scenario uncertainty, it is reasonable to assume that approaches and comments on model uncertainty are applicable to scenario uncertainty.

This paper responds to the need to account for changes in uncertainty magnitude when two, not one, equally valid models and two equally plausible scenarios are used to estimate risk and uncertainty. The objective is to develop a new method that adds model and scenario uncertainty to the conventional parameter uncertainty analysis of the cumulative risk assessment. We call this new inclusive method the scenario–model–parameter (SMP) uncertainty analysis. This paper focuses on the development of the SMP uncertainty analysis as an integral part of the cumulative risk assessment method. We begin with a review of essential concepts involving exposure, dose, and risk, including the new aggregate and cumulative risk concepts, continue with a review of uncertainty classification and uncertainty analysis processes, and conclude by formulating the SMP uncertainty analysis process. We demonstrate the application of this method with results from a related paper on the uncertainty of risk estimates from exposures to chlorpyrifos and diazinon using the National Human Exposure Assessment Survey in Arizona (NHEXAS-AZ) database (Karuchit and Moschandreas, 2001).

2. A synopsis of risk-related concepts

2.1. Exposure and dose

Definitions of exposure, dose and related terms used in this paper are those established in the EPA document "Guidelines for Exposure Assessment" (EPA, 1992a). The basic structure of the flow of an agent from the outer boundary to the receptor target organ and associated definitions are illustrated in Table 1 (EPA, 1992a). The onset of the scheme is the contact of a chemical agent with the outer boundary, which establishes an exposure. The outer boundaries of the inhalation route are the mouth and nose, and the outer boundary of the ingestion route is the mouth. In this scheme, there is no outer boundary of the dermal route, since the skin is the place where absorption takes place, and therefore it is an absorption barrier or exchange boundary, not an outer boundary. The route-specific boundaries, with corresponding chemical transfer process, are shown in Table 2 (EPA, 1992a).

The intake process commences when the chemical moves through the opening of the outer boundary. The amount of the chemical after crossing the outer boundary is called a *potential* dose. Inhalation dose, oral dose and dermal dose are common names for route-specific potential dose (EPA, 1992a). Potential dose is synonymous with *administered* dose. The amount that reaches the exchange boundary is called an *applied* dose (see Table 1). The uptake process takes place at the exchange boundary and involves absorption of the chemical through the skin or exposed tissues. The amount of chemical absorbed is called an *absorbed* dose, while the amount of chemical transported to an individual organ and the amount that reaches it are called a *delivered* dose and a *biologically effective* dose, respectively.

Although the above dose terms signify different quantities, they all have the same unit. The unit of dose has three