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ASPECTS OF UNCERTAINTY ANALYSIS IN ACCIDENT CONSEQUENCE MODELING

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Mathematical models are frequently used to determine probable dose to man from an accidental release of radionuclides by a nuclear facility. With increased emphasis on the accuracy of these models,[1,2] the incorporation of uncertainty analysis has become one of the most crucial and sensitive components in evaluating the significance of model predictions. In the present paper, we address three aspects of uncertainty in models used to assess the radiological impact to humans: uncertainties resulting from the natural variability in human biological parameters; the propagation of parameter variability by mathematical models; and comparison of model predictions to observational data.

HUMAN BIOLOGICAL VARIABILITY

To properly assess the potential impact on human health of an environmental pollutant, it is necessary to estimate dose to target organs resulting from specific exposure scenarios. Uncertainty in such estimates can arise in several ways. Two of the most important are nonuniform contact of individuals with the environment and the anatomical, physiological, and metabolic differences that occur between and within individuals over time.

Variations in organ dose distributions which result from nonuniform contact with the environment can be caused by local changes in environmental concentrations as well as differences in dietary and living habits. While these sources of uncertainty are important and must be carefully considered, we will not address them at this time. However, even assuming uniform environmental exposure to a pollutant, variations in biological parameters which control internal translocation and retention of radionuclides can result in considerable differences in organ doses. Cuddihy et al.[3] estimated variation in organ dose to dogs resulting from uniform exposure to inhalation of the metal cerium. In well-controlled inhalation studies with laboratory animals, they found that about 2% of the exposed animals received more than three times the average organ dose. Such measurements in humans are not feasible; however, autopsy data from a large urban hospital reveal wide variations in concentrations of trace metals found in human lung tissue.[4] For example, almost 3% of the samples contained mercury levels more than 11 times larger than the average concentration.

In models used to predict doses to specific organs, individuals are typically assumed to have an idealized average of physiological-anatomical characteristics, resulting in a model that is not representative of any specific individual. Considering the large variability present in individual characteristics, one might question whether or not dose estimates made with such models have any utility. We address this issue next.

PARAMETER VARIABILITY AND MODEL UNCERTAINTY

Analysis of the predictive variability of a model is concerned with impact of parameter variability on model predictions. The results of such an analysis provide not only the expected value of the prediction, but also the stochastic variability in the model predictions. A good example of this type of analysis is that performed by Hoffman and Baes[5] on a multiplicative chain model for prediction of the transport of molecular ^{131}I via the air-pasture-cow-milk-child's thyroid pathway. This pathway was chosen for analysis because the data base characterizing relevant parameters is probably the most extensive available for any radionuclide. While their analysis was predicated on assumptions of parameters with independent lognormal distributions, their conclusions illustrate the nature of complex models in several fundamental ways. One observation was that the probability distribution of dose to the thyroid was highly skewed, with the mean dose being approximately six times the estimated most probable dose. This skewness in the distribution produced by the model is characteristic of all models having stochastic variability in their parameters. Another observation was that even though the model had 12 parameters, each with variations of up to an order of magnitude, only about 3% of the predicted doses to individuals are more than 5 times the average dose. Similar results have been obtained in other studies.[6]

Studies of the propagation of parameter variability do not address the problem of whether a given model adequately reflects reality. This involves questions of whether any importance concepts were neglected during model development and whether the conceptual model is adequately represented in mathematical terms. These problems are best addressed through comparison of model predictions with actual observational data. This type of analysis is known as model validation. While validation studies are difficult to perform for internal dosimetry models, they have been done with environmental transport models. We give a brief review of these studies.

MODEL VALIDATION

Model validation consists of comparing output from a model with observational data. The object of this exercise is to provide a measure of the model's ability to predict the real processes being studied. Little and Miller[7] have surveyed the uncertainty in selected environmental transport models as determined by limited validation analysis. Their results and the reports of a Workshop on the Evaluation of Models used for the Environmental Assessment of Radionuclide Releases[1] indicate that aquatic transport models exhibit less variability in their estimates than other dispersion models. For instance, one-dimensional aquatic models of rivers and small lakes predict sediment concentrations within a factor of three, while two-dimensional models can predict particle pollutant concentrations within 40% and sediment concentrations within 70% when site-specific input data are available.

Validation of atmospheric dispersion models reveals that, under ideal conditions (flat terrain and steady meteorological conditions), they predict ground-level centerline concentrations at 10 km within 20% and concentrations in the entire 10-km radius within an order of magnitude. Although annual averages can usually be predicted within about a factor of two, larger uncertainties can be expected for acute releases during accident situations.

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