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Environmental Dose Reconstruction: Approaches to an Inexact Science*

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Abstract

The endpoints of environmental dose reconstruction are quantitative yet the science is inexact. Four problems related to this issue are described. These problems are: 1) Defining the scope of the assessment and setting logical priorities for detailed investigations, 2) Recognizing the influence of investigator judgment on the results, 3) Selecting an endpoint other than dose for the assessment of multiple contaminants, and 4) Resolving the conflict between credibility and expertise in selecting individuals responsible for dose reconstruction. Approaches are recommended for dealing with each of these problems.

Introduction

Recently, much attention has been given to the task of reconstructing doses and health risks to members of the public potentially exposed to contaminants released to the environment from government facilities operating during the 1940's through the 1970's. In many instances, detailed documentation of the release history and the ensuing environmental contamination is either missing or incomplete. The task of dose reconstruction is therefore heavily dependent on the use of mathematical models. These models are composed of equations and parameter values that represent a wide spectrum of physical, chemical, and biological processes. They are used with the aid of a computer to simulate past releases of contaminants, including the movement of materials through the environment via a variety of pathways from a source to a human receptor, and they are used to quantify biological insult in terms of dose or health risk. Needless to say, confidence in the results of these simulations is limited due to the fact that dose reconstruction is not an exact science.

Problem: The need to define the scope of the assessment and set priorities.

Initially, dose reconstruction issues are not well defined. The potential for human exposure may involve hundreds of contaminants and numerous environmental pathways leading to many identifiable subgroups of the population. The exposure pathways and lifestyles of the exposed individuals may depart substantially from the reference cases assumed in most computerized dose assessment models. Priority for investigation is frequently assigned to issues that are the most politically expedient. When steering panels are formed along disciplinary lines to establish priorities and set funding levels, each discipline will demand near equal attention in the dose reconstruction activity. This approach often leads to the misallocation of resources on issues that are of minor importance for determining the exposure and dose to population subgroups at highest risk.

Recommendation: Use a hierarchy of models to screen and prioritize.

When reviewing the issues and level of effort of work required for a dose reconstruction, it is prudent to apply a hierarchy of models in an iterative mode. The first iteration should be the use of relatively simple models designed for rapid screening. Screening should be used to rapidly bound potential exposures and risks to specific categories of individuals, without requiring large amounts of new data and extensive model refinement. Examples of screening models have been published by the International Atomic Energy Agency and the National Council on Radiological Protection and Measurements [1, 2].

Screening will usually show that only a few contaminants and exposure pathways are of dominant importance with respect to potential health risk of specific population subgroups [3]. Upper bound screening estimates should provide quantities that have a very low probability of underestimating actual exposures. Lower bound screening estimates should have a very low probability that actual doses are substantially

overestimated. These upper and lower bound screening estimates should then be compared with upper and lower dose or risk limits of concern.

If an upper bound screening estimate to a defined population subgroup is below an established lower limit of concern (for example, I will propose ≤ 1 mSv accumulated lifetime effective dose equivalent, or a lifetime risk of cancer incidence of $\leq 10^{-4}$) the situation should warrant low priority for further investigation. On the other hand, if a lower bound screening estimate exceeds an upper level of concern (e.g. > 100 mSv or > 10^{-2} lifetime cancer risk) high priority should be given to begin evaluation of the feasibility for an epidemiological follow-up. Establishing quantitative limits of concern may be among the most difficult tasks in the dose reconstruction activity, but without them it is nearly impossible to screen effectively.

After screening, the next iteration should involve the collection of data and modification of the model to permit a more "realistic assessment." To be defensible, the uncertainty associated with the prediction of a "realistic assessment" must be defined quantitatively. By identifying the parameters and submodels contributing most to this uncertainty, further justification can be made for more focused efforts to acquire data and to improve model structure in areas that will have the greatest impact on the dose estimate. These attempts to produce "realistic" estimates of dose should undergo several iterations, with each iteration leading to further requests for data and model improvement. This process should continue until either the magnitude of the uncertainty in the estimates becomes acceptably small or, for practical purposes, it becomes irreducible [4, 5].

Problem: Different investigators will produce different results.

Different results can be expected when the same problem is assigned to different investigators. These differences occur because proper initialization of a model to a given assessment problem requires the use of an extensive amount of judgment. Because of the need for judgment, different individuals applying the same computer code for dose reconstruction will generate different results, as long as they work

independently. This effect has been confirmed in recent international studies on environmental transfer models [6].

The importance of judgment is most apparent when quantitative estimates of uncertainty are requested. Quantifying uncertainties requires information and expertise external from that contained in a computer code. This information often spans many scientific disciplines. Expertise will differ from one group to another. Due to the uniqueness of each dose reconstruction problem, one cannot simply rely on uncertainty estimates published from a previous study or summarized in a handbook. Such information is often not relevant to the assessment situation under consideration [5,6,7]. Even when two different assessment teams produce near identical values for their "best estimate", two markedly different estimates of uncertainty can be expected (although they at least will overlap).

In the past, it has been expedient to designate a single party to carry out the assessment, using peer review panels and outside consultants to assure quality. Unfortunately, most peer review panels, which convene for relatively short periods at more or less infrequent intervals, concentrate their efforts on the logic of the overall approach and on the clarity with which results are presented and interpreted. Seldom do they have the time or resources to identify discrepancies by performing independent model calculations and uncertainty analyses.

Recommendation: Sponsor the intercomparison of independent assessments.

Especially important dose reconstruction questions should be independently approached by multiple (two or more) teams of scientists. An intercomparison of results, including uncertainty estimates, should then be made and discrepancies evaluated and resolved. The presentation and analysis of alternative assessment results will make the work of peer review panels more effective by rapidly pointing to areas of discrepancy. The eventual resolution of these discrepancies should add credibility to the

final analysis. Gains in credibility accomplished through this approach should more than offset apparent increases in cost.

Problem: Assessment of exposure to multiple types of contaminants requires another endpoint besides dose.

As long as dose reconstruction is concerned only with releases of radioactive substances, the endpoint of calculation can be the effective radiological dose-equivalent to the defined human receptor. The effective radiological dose-equivalent is (almost) directly related to health risk for all radionuclides. However, if other toxic substances are involved, endpoints other than dose must be considered. Without an endpoint that permits quantitative comparison, there is the danger of inappropriately weighting the importance of exposure to specific contaminants.

In the past, attempts have been made to simply compare environmental concentrations of contaminants in air and water to established regulatory concentration limits. Recent studies, however, have shown that regulations for different radioactive and chemical substances are grossly inconsistent with respect to similar types of health impact [8-11].

Recommendation: Health risk should be used instead of dose as a calculation endpoint for exposure to multiple contaminants.

This recommendation is currently being promoted by EPA Superfund Risk Assessment Guidance. For Superfund risk assessments, the lifetime risk of excess cancer incidence is used as an endpoint for both radionuclides and other chemical carcinogens [12, 13]. There is still a problem, however, with consistency in the derivation of risk conversion factors for radionuclides and chemicals.

The EPA risk conversion factors for radionuclides, unlike factors contained in publications by ICRP [14], BEIR V [15] and UNSCEAR 88 [16], are based on cancer incidence rather than mortality. These factors are best estimates

based primarily on (somewhat less current) interpretations of human epidemiological data. For chemical carcinogens, on the other hand, the EPA risk factors recommended for Superfund assessments are mostly 95% upper confidence bound extrapolations from laboratory animal studies. These discrepancies remain to be resolved.

More challenging is the task of developing a quantitative measure of health risk from exposure to non-carcinogenic toxic agents so that comparisons can be made with exposure to carcinogens. Currently, the evaluation of exposure to these two distinctly different types of contaminants is kept separate. This is a difficult issue. For most carcinogens, the cancer risk is assumed to be more or less a linear (multiplicative) function of dose. For non-carcinogens the health risk is highly non-linear with variations in type and severity of impact occurring at different levels of exposure. This non-linear relationship is dependent on the properties of the toxic agent, the amount and route of exposure, and the age and genetic makeup of the human receptor at the time of exposure.

The issue of age-dependency in exposure assessment is well known. Differences in age at the time of exposure can influence not only the magnitude of dose but also the probability of health risk. It becomes a major issue when either the total exposure time to a contaminant is short (on the order of a few years or less) or when the health impact is determined more by the rate at which dose is received than by the total accumulated dose. Published values used for EPA Superfund risk assessments based on lifetime exposures may not be applicable for dose reconstruction calculations, beyond that of initial screening.

Problem: Credibility Versus Expertise:

Because dose reconstruction relies on the use of judgment, scientists engaged in this activity should have the highest degree of credibility. It is extremely hard to find scientists in the U. S. A. who are acknowledged experts in radiological assessment who haven't worked extensively at some time in their careers for the Department of Energy or its predecessor, the

Atomic Energy Commission. Most if not all, of the computer codes currently used to assess exposure to radioactivity in the environment have either been directly funded by DOE or evolved from work performed at installations managed by DOE contractors. Often a dilemma develops between achieving independence from perceived DOE influence and compromising on scientific expertise.

Recommendation: Preserve credibility at all costs.

Establishing credibility is essential for public acceptance of the results of dose reconstruction. Objectivity and impartiality must take precedence over personal and political bias. Where necessary, expertise from outside the U.S.A should be solicited to avoid possible conflicts of interest. Here again, credibility can be enhanced by employing different groups to conduct independent calculations, with intercomparison of results leading to identification and resolution of discrepancies.

Finally, deliberate efforts should be made to encourage citizen involvement and participation. The practise of including citizen representatives on technical oversight panels has helped improve awareness of these panels to citizen concerns. It has also improved effective communication of technical results. The practice of open deliberations of the technical oversight panel and soliciting public comment at panel meetings has been a major step forward. Maintaining a high degree of scientific integrity while preserving credibility will be the ultimate challenge in environmental dose reconstruction given the inexact nature of the science.

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