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GUIDANCE FOR RISK CHARACTERIZATION

U.S. Environmental Protection Agency
Science Policy Council
February, 1995

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PREFACE

This guidance contains principles for developing and describing EPA risk assessments, with a particular emphasis on risk characterization. The current document is an update of the guidance issued with the Agency's 1992 policy (Guidance on Characterization for Risk Managers and Risk Assessors, February 26, 1992). The guidance has not been substantially revised, but includes some clarifications and changes to give more prominence to certain issues, such as the need to examine the use of default assumptions.

As in the 1992 policy, some aspects of this guidance focus on cancer risk assessment, but the guidance applies general human health effects (e.g., neurotoxicity, developmental toxicity) and, with appropriate modifications, should be used in all human health risk assessments. This document has not been revised to specifically address ecological risk assessment, however initial guidance for ecological risk characterization is included in EPA's Framework for Ecological Risk Assessments (EPA/630/R-92/001). Neither does this guidance address in detail the use of risk assessment information (e.g., information from the Integrated Risk Information System (IRIS)) to generate site- or media-specific risk assessments. Additional program specific guidance will be developed to enable implementation of EPA's Risk Characterization Policy. Development of such guidance will be overseen by the Science Policy Council and will involve risk assessors and risk managers from across the Agency.

I. THE RISK ASSESSMENT RISK MANAGEMENT INTERFACE

Recognizing that for many people the term risk assessment has wide meaning, the National Research Council's 1983 report on risk assessment in the federal government distinguished between risk assessment and risk management.

"Broader uses of the term [risk assessment] than ours also embrace analysis of perceived risks, comparisons of risks associated with different regulatory strategies, and occasionally analysis of the economic and social implications of regulatory decisions functions that we assign to risk management (emphasis added). (1)

In 1984, EPA endorsed these distinctions between risk assessment and risk management for Agency use (2), and later incorporated them in developing risk assessment guidelines (3). In 1994, the NRC reviewed the Agency's approach to and use of risk

assessment and issued an extensive report on their findings (4). This distinction suggests that EPA participants in the process can be grouped into two main categories, each with somewhat different responsibilities, based on their roles with respect to risk assessment and risk management.

A. Roles of Risk Assessors and Risk Managers

Within the Risk Assessment category there is a group that develops chemical-specific risk assessments by collecting, analyzing, and synthesizing scientific data to produce the hazard identification, dose-response, and exposure assessment portion of the risk assessment and to characterize risk. This group relies in part on Agency risk assessment guidelines to address science policy issues and scientific uncertainties. Generally, this group includes scientists and statisticians in the Office of Research and Development; the Office of Prevention, Pesticides and Toxics and other program offices; the Carcinogen Risk Assessment Verification Endeavor (CRAVE); and the Reference Dose (RfD) and Reference Concentration (RfC) Workgroups.

Another group generates site or media-specific risk assessments for use in regulation development or site-specific decision making. These assessors rely on existing databases (e.g., IRIS, ORD Health Assessment Documents, CRAVE and RfD, Workgroup documents, and program-specific toxicity information) and media- or site-specific exposure information in developing risk assessments. This group also relies in part on Agency risk assessment guidelines and program-specific guidance to address science policy issues and scientific uncertainties. Generally, this group includes scientists and analysts in program offices, regional offices, and the Office of Research and Development.

Risk managers, as a separate category, integrate the risk characterization with other considerations specified in applicable statutes to make and justify regulatory decisions. Generally, this group includes Agency managers and decisionmakers. Risk managers also play a role in determining the scope of risk assessments. The risk assessment process involves regular interaction between risk assessors and risk managers, with overlapping responsibilities at various stages in the process. Shared responsibilities include initial decisions regarding the planning and conduct of an assessment, discussions as the assessment develops, decisions regarding new data needed to complete an assessment and to address significant uncertainties. At critical junctures in the assessment, such consultations shape the nature of, and schedule for, the assessment. External experts and members of the public may also play a role in determining the scope of the assessment. For example, the public is often concerned about certain chemicals or exposure pathways in the development of site-specific risk assessments.

B. Guiding Principles

The following guidance outlines principles for those who generate, review, use, and integrate risk assessments for decision making.

1. Risk assessors and risk managers should be sensitive to distinctions between risk assessment and risk management.

The major participants in the risk assessment process have many shared responsibilities. Where responsibilities differ, it is important that participants confine themselves to tasks in their areas of responsibility and not inadvertently obscure differences between risk assessment and risk management.

For the generators of the assessment, distinguishing between risk assessment and risk management means that scientific information is selected, evaluated, and presented without considering issues such as cost, feasibility, or how the scientific analysis might influence the regulatory or site-specific decision. Assessors are charged with (1) generating a credible, objective, realistic, and scientifically balanced analysis; (2) presenting information on hazard, dose-response, exposure and risk; and (3) explaining confidence in each assessment by clearly delineating strengths, uncertainties and assumptions, along with the impacts of these factors (e.g., confidence limits, use of conservative/non-conservative assumptions) on the overall assessment. They do not make decisions on the acceptability of any risk level for protecting public health or selecting procedures for reducing risks.

For users of the assessment and for decisionmakers who integrate these assessments into regulatory or site-specific decisions, the distinction between risk assessment and risk management means refraining from influencing the risk description through consideration of other factors e.g., the regulatory outcome and from attempting to shape the risk assessment to avoid statutory constraints, meet regulatory objectives, or serve political purposes. Such management considerations are often legitimate considerations for the overall regulatory decision (see next principle), but they have no bearing on estimating or describing risk. However, decisionmakers and risk assessors participate in an Agency process that establishes policy directions that determine the overall nature and tone of Agency risk assessments and, as appropriate,

provide policy guidance on difficult and controversial risk assessment issues. Matters such as risk assessment priorities, degree of conservatism, and acceptability of particular risk levels are reserved for decisionmakers who are charged with making decisions regarding protection of public health.

2. The risk assessment product, that is, the risk characterization, is only one of several kinds of information used in regulatory decision-making.

Risk characterization, the last step in risk assessment, is the starting point for risk management considerations and the foundation for regulatory decision-making, but it is only one of several important components in such decisions. As the last step in risk assessment, the risk characterization identifies and highlights the noteworthy risk conclusions and related uncertainties. Each of the environmental laws administered by EPA calls for consideration of other factors at various stages of the regulatory process. As authorized by different statutes, decisionmakers evaluate technical feasibility (e.g., treatability detection limits), economic, social, political, and legal factors as part of the analysis of whether or not to regulate and, if so, to what extent. Thus, regulatory decisions are usually based on a combination of the technical analysis used to develop the assessment and information from other fields.

For this reason, risk assessors and managers should understand that the regulatory decision is usually not determined solely by the outcome of the risk assessment. For example, a regulatory decision on the use of a particular pesticide considers not only the risk level to affected populations, but also the agricultural benefits of its use that may be important for the nation's food supply. Similarly, assessment efforts may produce an RfD for a particular chemical, but other considerations may result in a regulatory level that is more or less protective than the RfD itself.

For decisionmakers, this means that societal considerations (e.g., costs and benefits) that, along with the risk assessment, shape the regulatory decision should be described as fully as the scientific information set forth in the risk characterization. Information on data sources and analyses, their strengths and limitations, confidence in the assessment, uncertainties, and alternative analyses are as important here as they are for the scientific components of the regulatory decision. Decisionmakers should be able to expect, for example, the same level of rigor from the economic analysis as they receive from the risk analysis. Risk management decisions involve numerous assumptions and uncertainties regarding technology, economic and social factors, which need to be explicitly identified for the decisionmakers and the public.

II. RISK CHARACTERIZATION

A. Defining Risk Characterization in the Context of Risk Assessment

EPA risk assessment principles and practices draw on many sources. Obvious sources include the environmental laws administered by EPA, the National Research Council's 1983 report on risk assessment (1), the Agency's Risk Assessment Guidelines (3), and various program specific guidance (e.g., the Risk Assessment Guidance for Superfund). Twenty years of EPA experience in developing, defending, and enforcing risk assessment based regulation is another. Together these various sources stress the importance of a clear explanation of Agency processes for evaluating hazard, dose-response, exposure, and other data that provide the scientific foundation for characterizing risk.

This section focuses on two requirements for full characterization of risk. First, the characterization should address qualitative and quantitative features of the assessment. Second, it should identify the important strengths and uncertainties in the assessment as part of a discussion of the confidence in the assessment. This emphasis on a full description of all elements of the assessment draws attention to the importance of the qualitative, as well as the quantitative, dimensions of the assessment. The 1983 NRC report carefully distinguished qualitative risk assessment from quantitative assessments, preferring risk statements that are not strictly numerical.

The term risk assessment is often given narrower and broader meanings than we have adopted here. For some, the term is synonymous with quantitative risk assessment and emphasizes reliance on numerical results. Our broader definition includes quantification, but also includes qualitative expressions of risk. Quantitative estimates of risk are not always feasible, and they may be eschewed by agencies for policy reasons. (1)

EPA's Exposure Assessment Guidelines define risk characterization as the final step in the risk assessment process that

- Integrates the individual characterizations from the hazard identification, dose-response, and exposure assessments;
- Provides an evaluation of the overall quality of the assessment and the degree of confidence the authors have in their estimates of risk and conclusions drawn;
- Describes risks to individuals and populations in terms of extent and severity of probable harm; and
- Communicates results of the risk assessment to the risk manager. (5)

Particularly critical to full characterization of risk is a frank and open discussion of the uncertainty in the overall assessment and in each of its components. The uncertainty discussion is important for several reasons.

1. Information from different sources carries different kinds of uncertainty and knowledge of these differences is important when uncertainties are combined for characterizing risk.
2. The risk assessment process, with management input, involves decisions regarding the collection of additional data (versus living with uncertainty); in the risk characterization, a discussion of the uncertainties will help to identify what additional information could contribute significantly to reducing uncertainties in risk assessment.
3. A clear and explicit statement of the strengths and limitations of a risk assessment requires a clear and explicit statement of related uncertainties.

A discussion of uncertainty requires comment on such issues as the quality and quantity of available data, gaps in the data base for specific chemicals, quality of the measured data, use of default assumptions, incomplete understanding of gene biological phenomena, and scientific judgments or science policy positions that were employed to bridge information gaps.

In short, broad agreement exists on the importance of a full picture of risk, particularly including a statement of confidence in the assessment and the associated uncertainties. This section discusses information content and uncertainty aspects of risk characterization, while Section III discusses various descriptors used in risk characterization.

B. Guiding Principles

1. The risk characterization integrates the information from the hazard identification, dose-response, and exposure assessments, using a combination of qualitative information, quantitative information, and information regarding uncertainties.

Risk assessment is based on a series of questions that the assessor asks about the data and the implications of the data for human risk. Each question calls for analysis and interpretation of the available studies, selection of the data that are most scientifically reliable and most relevant to the problem at hand, and scientific conclusions regarding the question presented. As suggested below, because the questions and analyses are complex, a complete characterization includes several different kinds of information, carefully selected for reliability and relevance.

a. Hazard Identification What is known about the capacity of an environmental agent for causing cancer (or other adverse effects) in humans and laboratory animals?

Hazard identification is a qualitative description based on factors such as the kind and quality of data on humans or laboratory animals, the availability of ancillary information (e.g., structure-activity analysis, genetic toxicity, pharmacokinetics) from other studies, and the weight of the evidence from all of these data sources. For example, to develop this description, the issues addressed include:

- 1) the nature, reliability, and consistency of the particular studies in humans and in laboratory animals;
- 2) the available information on the mechanistic basis for activity; and
- 3) experimental animal responses and their relevance to human outcomes.

These issues make clear that the task of hazard identification is characterized by describing the full range of available information and the implications of that information for human health.

b. Dose-Response Assessment What is known about the biological mechanisms and dose-response relationships underlying any effects observed in the laboratory or epidemiology studies providing data for the assessment?

The dose response assessment examines quantitative relationships between exposure (or dose) and effects in the studies used to identify and define effects of concern. This information is later used along with "real world" exposure information (below) to develop estimates of the likelihood of adverse effects in populations potentially at risk. It should be noted that, in practice, hazard identification for developmental toxicity and other non-cancer health effects is usually done in conjunction with an evaluation of dose-response relationships, since the determination of whether there is a hazard is often dependent on whether a dose response relationship is present. (6) Also, the framework developed by EPA for ecological risk assessment

does not distinguish between hazard identification and dose-response assessment, but rather calls for a "characterization of ecological effects." (7)

Methods for establishing dose-response relationships often depend on various assumptions used in lieu of a complete data base, and the method chosen can strongly influence the overall assessment. The Agency's risk assessment guidelines call for identifying so-called "default assumptions" for use in the absence of other information. The risk assessment should pay careful attention to the choice of a high-to-low dose extrapolation procedure. As a result, an assessor who is characterizing a dose-response relationship considers several key issues:

- 1) the relationship between extrapolation models selected and available information on biological mechanisms;
- 2) how appropriate data sets were selected from those that show the range of possible potencies both in laboratory animals and humans;
- 3) the basis for selecting interspecies dose scaling factors to account for scaling doses from experimental animals to humans;
- 4) the correspondence between the expected route(s) of exposure and the exposure route(s) utilized in the studies forming the basis of the dose-response assessment, as well as the interrelationships of potential effects from different exposure routes;
- 5) the correspondence between the expected duration of exposure and the exposure durations in the studies used in the basis of the dose-response assessment, e.g., chronic studies would be used to assess long-term, cumulative exposure concentrations, while acute studies would be used in assessing peak levels of exposure; and
- 6) the potential for differing susceptibilities among population subgroups.

The Agency's Integrated Risk Information System (IRIS) is a repository for such information for EPA. EPA program offices also maintain program-specific databases, such as the OSWER Health Effects Assessment Summary Tables (HEAST). IRIS includes data summaries representing Agency consensus on specific chemicals, based on a careful review of the scientific issues listed above. For specific risk assessments based on data from any source, risk assessors should carefully review information presented, emphasizing confidence in the data and uncertainties (see subsection 2 below). Specifically, when IRIS data are used, the IRIS statement of confidence should be included as an explicit part of the risk characterization for hazard and dose-response information.

c. Exposure Assessment What is known about the principal paths, patterns, and magnitudes of human exposure and number of persons who may be exposed?

The exposure assessment examines a wide range of exposure parameters pertaining to the environmental scenarios of people who may be exposed to the agent under study. The information considered for the exposure assessment includes monitoring studies of chemical concentrations in environmental media, food, and other materials; modeling of environmental fate and transport of contaminants; and information on different activity patterns of different population subgroups. An assessor who characterizes exposure should address several issues:

- 1) The basis for the values and input parameters used for each exposure scenario. If the values are based on data, there should be a discussion of the quality, purpose, and representativeness of the database. For monitoring data, there should be a discussion of the data quality objectives as they are relevant to risk assessment, including the appropriateness of the analytical detection limits. If models are applied, the appropriateness of the models and information on their validation should be presented. When assumptions are made, the source and general logic used to develop the assumptions (e.g., program guidance, analogy, professional judgment) should be described.
- 2) The confidence in the assumptions made about human behavior and the relative likelihood of the different exposure scenarios.
- 3) The major factor or factors (e.g., concentration, body uptake, duration/frequency of exposure) thought to account for the greatest uncertainty in the exposure estimate, due either to sensitivity or lack of data.
- 4) The link between the exposure information and the risk descriptors discussed in Section III of this Appendix. Specifically, the risk assessor needs to discuss the connection between the conservatism or non-conservatism of the data/assumptions used in the scenarios and the choice of descriptors.

5) Other information that may be important for the particular risk assessment. For example, for many assessments, other sources and background levels in the environment may contribute significantly to population exposures and should be discussed.

2) The risk characterization includes a discussion of uncertainty and variability.

In the risk characterization, conclusions about hazard and dose response are integrated with those from the exposure assessment. In addition, confidence about these conclusions, including information about the uncertainties associated with each aspect of the assessment in the final risk summary, is highlighted. In the previous assessment steps and in the risk characterization, the risk assessor must distinguish between variability and uncertainty.

Variability arises from true heterogeneity in characteristics such as dose-response differences within a population, or differences in contaminant levels in the environment. The values of some variables used in an assessment change with time and space, or across the population whose exposure is being estimated. Assessments should address the resulting variability in doses received by members of the target population. Individual exposure, dose, and risk can vary widely in a large population. The central tendency and high end individual risk descriptors (discussed in Section III below) are intended to capture the variability in exposure, lifestyles, and other factors that lead to a distribution of risk across a population.

Uncertainty, on the other hand, represents lack of knowledge about factors such as adverse effects or contaminant level which may be reduced with additional study. Generally, risk assessments carry several categories of uncertainty, and each merits consideration. Measurement uncertainty refers to the usual error that accompanies scientific measurements--standard statistical techniques can often be used to express measurement uncertainty. A substantial amount of uncertainty is often inherent in environmental sampling, and assessments should address these uncertainties. There are likewise uncertainties associated with the use of scientific models, e.g., dose-response models, models of environmental fate and transport. Evaluation of model uncertainty would consider the scientific basis for the model and available empirical validation.

A different kind of uncertainty stems from data gaps that is, estimates or assumptions used in the assessment. Often, the data gap is broad, such as the absence of information on the effects of exposure to a chemical on humans or on the biological mechanism of action of an agent. The risk assessor should include a statement of confidence that reflects the degree to which the risk assessor believes that the estimates or assumptions adequately fill the data gap. For some common and important data gaps, Agency or program-specific risk assessment guidance provides default assumptions or values. Risk assessors should carefully consider all available data before deciding to rely on default assumptions. If defaults are used in risk assessment should reference the Agency guidance that explains the default assumptions or values.

Often risk assessors and managers simplify discussion of risk issues by speaking only of the numerical components of an assessment. That is, they refer to the alpha-numeric weight-of-the-evidence classification, unit risk, the risk-specific dose the q_1^* for cancer risk, and the RfD/RfC for health effects other than cancer, to the exclusion of other information bearing on the risk case. However, since every assessment carries uncertainties, a simplified numerical presentation of risk is always incomplete and often misleading. For this reason, the NRC (1) and EPA risk assessment guidelines (2) call for "characterizing" risk to include qualitative information, a related numerical risk estimate and a discussion of uncertainties, limitations, and assumptions--default and otherwise.

Qualitative information on methodology, alternative interpretations, and working assumptions (including defaults) is an important component of risk characterization. For example, specifying that animal studies rather than human studies were used in an assessment tells others that the risk estimate is based on assumptions about human response to a particular chemical rather than human data. Information that human exposure estimates are based on the subjects' presence in the vicinity of a chemical accident rather than tissue measurements defines known and unknown aspects of the exposure component of the study.

Qualitative descriptions of this kind provide crucial information that augments understanding of numerical risk estimates. Uncertainties such as these are expected in scientific studies and in any risk assessment based on these studies. Such uncertainties do not reduce the validity of the assessment. Rather, they should be highlighted along with other important assessment conclusions to inform others fully on the results of the assessment.

In many cases, assessors must choose among available data, models, or assumptions in estimating risks. Examining the impact of selected, plausible alternatives on the conclusions of the assessment is an important part of the uncertainty discussion. The key words are "selected" and "plausible;" listing all alternatives to a particular assumption, regardless of their merits would be superfluous. Generators of the assessment, using best professional judgment, should outline the strengths and weaknesses of the plausible alternative approaches.¹

An adequate description of the process of alternatives selection involves several aspects.

- a. A rationale for the choice.
- b. Discussion of the effects of alternatives selected on the assessment.
- c. Comparison with other plausible alternatives, where appropriate.

The degree to which variability and uncertainty are addressed depends largely on the scope of the assessment and the resources available. For example, the Agency does not expect an assessment to evaluate and assess every conceivable exposure scenario for every possible pollutant, to examine all susceptible populations potentially at risk, or to characterize every possible environmental scenario to estimate the cause and effect relationships between exposure to pollutants and adverse health effects. Rather, the discussion of uncertainty and variability should reflect the type and complexity of the assessment, with the level of effort for analysis and discussion of uncertainty corresponding to the level of effort for the assessment.

3. Well balanced risk characterizations present risk conclusions and information regarding the strengths and limitations of the assessment for other risk assessors, EPA decision makers, and the public.

The risk assessment process calls for identifying and highlighting significant risk conclusions and related uncertainties to assure full communication among risk assessors and partly to assure that decisionmakers are fully informed. Issues are identified by acknowledging noteworthy qualitative and quantitative factors that make a difference in the overall assessment of hazard and risk, and hence in the ultimate regulatory decision. The key word is "noteworthy." Information that significantly influences the analysis is explicitly noted in all future presentations of the risk assessment and in the related decision. Uncertainties and assumptions that strongly influence confidence in the risk estimate also require special attention.

Numerical estimates should not be separated from the descriptive information that is integral to risk characterization. Documents and presentations supporting regulatory or site-specific decisions should include both the numerical estimate and descriptive information; in short reports, this information can be abbreviated. Fully visible information assures that important features of the assessment are immediately available at each level of review for evaluating whether risks are acceptable or unreasonable.

III. EXPOSURE ASSESSMENT AND RISK DESCRIPTORS

A. Presentation of Risk Descriptors

The results of a risk assessment are usually communicated to the risk manager in the risk characterization portion of the assessment. This communication is often accomplished through risk descriptors which convey information and answer questions about risk, each descriptor providing different information and insights. Exposure assessment plays a key role in developing these risk descriptors since each descriptor is based in part on the exposure distribution within the population of interest.

The following guidance outlines the different descriptors in a convenient order that should not be construed as a hierarchy of importance. These descriptors should be used to describe risk in a variety of ways for a given assessment, consistent with the assessment's purpose, the data available, and the information the risk manager needs. Use of a range of descriptors instead of a single descriptor enables Agency programs to present a picture of risk that corresponds to the range of different exposure conditions encountered for most environmental chemicals. This analysis, in turn, allows risk managers to identify populations at greater and lesser risk and to shape regulatory solutions accordingly.

Agency risk assessments will be expected to address or provide descriptions of (1) individual risk that include the central tendency and high end portions of the risk distribution, (2) population risk, and (3) important subgroups of the population such as highly exposed or highly susceptible groups. Assessors may also use additional descriptors of risk as needed where these add to the clarity of the presentation. With the exception of assessments where particular descriptors clearly do not apply, some form of these three types of descriptors should be routinely developed and presented for Agency risk assessments². In other cases, where a descriptor would be relevant, but the program lacks the data or methods to develop the program office should design and implement a plan, in coordination with other EPA offices, to meet these assessment needs. While gaps continue to exist, risk assessors should make their best efforts to address each risk descriptor, and a minimum, should briefly discuss the lack of data or methods. Finally, presenters of risk assessment information should be prepared to routinely answer questions by risk managers concerning these descriptors.

It is essential that presenters not only communicate the results of the assessment by addressing each of the descriptors where appropriate, but that they also communicate their confidence that these results portray a reasonable picture of the actual or projected exposures. This task will usually be accomplished by frankly commenting on the key assumptions and parameters that have the greatest impact on the results, the basis or rationale for choosing these assumptions/parameters and the consequences of choosing other assumptions.

B. Relationship Between Exposure Descriptors and Risk Descriptors

In the risk assessment process, risk is estimated as a function of exposure, with the risk of adverse effects increasing as exposure increases. Information on the levels of exposure experienced by different members of the population is key to understanding the range of risks that may occur. Risk assessors and risk managers should keep in mind, however, that exposure is not synonymous with risk. Differences among individuals in absorption rates, susceptibility, or other factors that individuals with the same level of exposure may be at different levels of risk. In most cases, the state of the science is yet inadequate to define distributions of factors such as population susceptibility. The guidance principles below discuss a variety of risk descriptors that primarily reflect differences in estimated exposure. If a full description of the range of susceptibility in the population cannot be presented, an effort should be made to identify subgroups that, for various reasons, may be particularly susceptible.

C. Guiding Principles

1. Information about the distribution of individual exposures is important to communicating the results of a risk assessment.

The risk manager is generally interested in answers to questions such as the following:

- Who are the people at the highest risk?
- What risk levels are they subjected to?
- What are they doing, where do they live, etc., that might be putting them at this higher risk?
- What is the average risk for individuals in the population of interest?

Individual exposure and risk descriptors are intended to provide answers to these questions so as to illuminate the risk management decisions that need to be made. In order to describe the range of risks, both high end and central tendency descriptors are used to convey the variability in risk levels experienced by different individuals in the population.

a. High end descriptor

For the Agency's purposes, high end risk descriptors are plausible estimates of the individual risk for those persons at the upper end of the risk distribution. Given limitations in current understanding of variability in individuals' sensitivity to toxins, high end descriptors will usually address high end exposure or dose (herein referred to as exposure for brevity). The intent of these descriptors is to convey estimates of exposure in the upper range of the distribution, but to avoid estimates which go beyond the true distribution. Conceptually, high end exposure means exposure above about the 90th percentile of the population distribution, but not higher than the individual in the population who has the highest exposure. When large populations are assessed, a large number of individuals may be included within the "high end" (e.g., above 90th or 95th percentile) and information on the range of exposures received by these individuals should be presented.

High end descriptors are intended to estimate the exposures that are expected to occur in small, but definable, "high end" segments of the subject population.³ The individuals with these exposures may be members of a special population segment or individuals in the general population who are highly exposed because of the inherent stochastic nature of the factors that give rise to exposure. Where differences in sensitivity can be identified within the population, high end estimates address sensitive individuals or subgroups can be developed.

In those few cases in which the complete data on the population distributions of exposures and doses are available, high end exposure or dose estimates can be represented by reporting exposures or doses at a set of selected percentiles of the distributions, such as the 90th, 95th, and 98th percentile. High end exposures or doses, as appropriate, can then be used to calculate high end risk estimates.

In the majority of cases where the complete distributions are not available, several methods help estimate a high end exposure or dose. If sufficient information about the variability in chemical concentrations, activity patterns, or other factors are available, the distribution may be estimated through the use of appropriate modeling (e.g., Monte Carlo simulation or

parametric statistical methods). The determination of whether available information is sufficient to support the use of probabilistic estimation methods requires careful review and documentation by the risk assessor. If the input distributions based on limited data, the resulting distribution should be evaluated carefully to determine whether it is an improvement over traditional estimation techniques. If a distribution is developed, it should be described with a series of percentiles or population frequency estimates, particularly in the high end range. The assessor and risk manager should be aware, however, that unless a great deal is known about exposures and doses at the high end of the distribution, these estimates involve considerable uncertainty which the exposure assessor will need to describe. Note that in this context, the probabilistic analysis addresses variability of exposure in the population. Probabilistic techniques may also be applied to evaluate uncertainty in estimates (see section 5, below). However, it is generally inappropriate to combine distributions reflecting uncertainty and variability to get a single overall distribution. Such a result is not readily interpretable for the concerns of environmental decision-making.

If only limited information on the distribution of the exposure or dose factors is available, the assessor should approach estimating the high end by identifying the most sensitive variables and using high end values for a subset of these variables leaving others at their central values.⁴ In doing this, the assessor needs to avoid combinations of parameter values that are inconsistent (e.g., low body weight used in combination with high dietary intake rates), and must keep in mind the ultimate objective of being within the distribution of actual expected exposures and doses, and not beyond it.

If very little data are available on the ranges for the various variables, it will be difficult to estimate exposures or doses or associated risks in the high end with much confidence. One method that has been used in such cases is to start with a bounding estimate and "back off" the limits used until the combination of parameter values is, in the judgment of the assessor, within the distribution of expected exposure, and still lies within the upper 10% of persons exposed. Obviously, this method results in a large uncertainty and requires explanation.

b. Central tendency descriptor

Central tendency descriptors generally reflect central estimates of exposure or dose. The descriptor addressing central tendency may be based on either the arithmetic mean exposure (average estimate) or the median exposure (median estimate), either of which should be clearly labeled. The average estimate, used to approximate the arithmetic mean, can often be derived by using average values for all the exposure factors.⁵ It does not necessarily represent a particular individual on the distribution. Because of the skewness of typical exposure profiles, the arithmetic mean may differ substantially from the median estimate (i.e., 50th percentile estimate, which is equal to the geometric mean for a log normal distribution). The selection of which descriptor(s) to present in the risk characterization will depend on the available data and the goals of the assessment. When data are limited, it may not be possible to construct true median or mean estimates, but it is still possible to construct estimates of central tendency. The discussion of the use of probabilistic techniques in Section 1(a) above also applies to estimates of central tendency.

2. Information about population exposure leads to another important way to describe risk.

Population risk refers to an assessment of the extent of harm for the population as a whole. In theory, it can be calculated by summing the individual risks for all individuals within the subject population. This task, of course, requires a great deal more information than is normally, if ever, available.

The kinds of questions addressed by descriptors of population risk include the following:

- How many cases of a particular health effect might be probabilistically estimated in this population for a specific time period?
- For non-carcinogens, what portion of the population is within a specified range of some reference level; e.g., exceedance of the RfD (a dose), the RfC (a concentration), or other health concern level?
- For carcinogens, what portion of the population is above a certain risk level, such as 10^{-6} ?

These questions can lead to two different descriptors of population risk.

a. Probabilistic number of cases

The first descriptor is the probabilistic number of health effect cases estimated in the population of interest over a specific time period. This descriptor can be obtained either by (a) summing the individual risks over all the individuals in the population, e.g. using an estimated distribution of risk in the population, when such information is available, or (b) through the use of a risk model that assumes a linear nonthreshold response to exposure, such as many carcinogenic models. In these

calculations, data will typically be available to address variability in individual exposures. If risk varies linearly with exposure, multiplying the mean risk by the population size produces an estimate of the number of cases.⁶ At the present time, most cancer potency values represent plausible upper bounds on risk. When such a value is used to estimate numbers of cancer cases, it is important to understand that the result is also an upper bound. As with other risk descriptors, this approach may not adequately address sensitive subgroups for which different dose-response curves or exposure estimates might be needed.

Obviously, the more information one has, the more certain the estimate of this risk descriptor, but inherent uncertainties in assessment methodology place limitations on the accuracy of the estimate. The discussion of uncertainty involved in estimating the number of cases should indicate that this descriptor is not to be confused with an actuarial prediction of cases in the population (which is a statistical prediction based on a great deal of empirical data).

In general, it should be recognized that when small populations are exposed, population risk estimates may be very small. For example, if 100 people are exposed to an individual lifetime cancer risk of 10^{-4} , the expected number of cases is 0.01. In such situations, individual risk estimates will usually be a more meaningful parameter for decision-makers.

b. Estimated percentage of population with risk greater than some level

For noncancer effects, we generally have not developed the risk assessment techniques to the point of knowing how to estimate risk probabilities, so a second descriptor is usually more appropriate: An estimate of the percentage of the population, or number of persons, above a specified level of risk or within a specified range of some reference level, e.g., exceedance of the RfD or the RfC, LOAEL, or other specific level of interest. This descriptor must be obtained through measuring or simulating the population distribution.

3. Information about the distribution of exposure and risk for different subgroups of the population are important components of a risk assessment.

A risk manager might also ask questions about the distribution of the risk burden among various segments of the subject population such as the following: How do exposure and risk impact various subgroups?; and, what is the population risk for a particular subgroup? Questions about the distribution of exposure and risk among such population segments require additional risk descriptors.

a. Highly exposed

Highly exposed subgroups can be identified, and where possible, characterized and the magnitude of risk quantified. This descriptor is useful when there is (or is expected to be) a subgroup experiencing significantly different exposures or doses from that of the larger population. These sub-populations may be identified by age, sex, lifestyle, economic factors, or other demographic variables. For example, toddlers who play in contaminated soil and high fish consumers represent sub-populations that may have greater exposures to certain agents.

b. Highly susceptible

Highly susceptible subgroups can also be identified, and if possible, characterized and the magnitude of risk quantified. This descriptor is useful when the sensitivity or susceptibility to the effect for specific subgroups is (or is expected to be) significantly different from that of the larger population. In order to calculate risk for these subgroups, it will sometimes be necessary to use a different dose-response relationship; e.g., upon exposure to a chemical, pregnant women, elderly people, children, and people with certain illnesses may each be more sensitive than the population as a whole. For example, children are thought to be both highly exposed and highly susceptible to the effects of environmental lead. A model has been developed that uses data on lead concentrations in different environmental media to predict the resulting blood lead levels in children. Federal agencies are working together to develop specific guidance on blood lead levels that present risks to children.

It is important to note, however, that the Agency's current methodologies for developing reference doses and reference concentrations (RfDs and RfCs) are designed to protect sensitive populations. If data on sensitive human populations are available (and there is confidence in the quality of the data), then the RfD is set at the dose level at which no adverse effects are observed in the sensitive population (e.g., RfDs for fluoride and nitrate). If no such data are available (for example, if an RfD is developed using data from humans of average or unknown sensitivity) then an additional 10-fold factor is used to account for variability between the average human response and the response of more sensitive individuals.

Generally, selection of the population segments is a matter of either a priori interest in the subgroup (e.g., environmental

justice considerations), in which case the risk assessor and risk manager can jointly agree on which subgroups to highlight a matter of discovery of a sensitive or highly exposed subgroup during the assessment process. In either case, once identified, the subgroup can be treated as a population in itself, and characterized in the same way as the larger population using the descriptors for population and individual risk.

4. Situation-specific information adds perspective on possible future events or regulatory options.

"What if...?" questions can be used to examine candidate risk management options. For example, consider the following

- What if a pesticide applicator applies this pesticide without using protective equipment?
- What if this site becomes residential in the future?
- What risk level will occur if we set the standard at 100 ppb?

Answering these "What if...?" questions involves a calculation of risk based on specific combinations of factors postulated within the assessment⁷. The answers to these "What if...?" questions do not, by themselves, give information about how the combination of values might be in the actual population or about how many (if any) persons might be subjected to the potential future risk. However, information on the likelihood of the postulated scenario would also be desirable to include the assessment.

When addressing projected changes for a population (either expected future developments or consideration of different regulatory options), it is usually appropriate to calculate and consider all the risk descriptors discussed above. When central tendency or high end estimates are developed for a future scenario, these descriptors should reflect reasonable expectations about future activities. For example, in site-specific risk assessments, future scenarios should be evaluated when they are supported by realistic forecasts of future land use, and the risk descriptors should be developed within that context.

5. An evaluation of the uncertainty in the risk descriptors is an important component of the uncertainty discussion in the assessment.

Risk descriptors are intended to address variability of risk within the population and the overall adverse impact on the population. In particular, differences between high end and central tendency estimates reflect variability in the population, not the scientific uncertainty inherent in the risk estimates. As discussed above, there will be uncertainty in all estimates of risk. These uncertainties can include measurement uncertainties, modeling uncertainties, and assumptions to fill data gaps. Risk assessors should address the impact of each of these factors on the confidence in the estimated risk values.

Both qualitative and quantitative evaluations of uncertainty provide useful information to users of the assessment. The techniques of quantitative uncertainty analysis are evolving rapidly and both the SAB (8) and the NRC (4) have urged the Agency to incorporate these techniques into its risk analyses. However, it should be noted that a probabilistic assessment that uses only the assessor's best estimates for distributions of population variables addresses variability, but not uncertainty. Uncertainties in the estimated risk distribution need to be separately evaluated.

FOOTNOTES

¹ In cases where risk assessments within an Agency program routinely address similar sets of alternatives, program guidance may be developed to streamline and simplify the discussion of these alternatives.

² Program-specific guidance will need to address these situations. For example, for site-specific assessments, the utility and appropriateness of population risk estimates will be determined based on the available data and program guidance.

³ High end estimates focus on estimates of exposure in the exposed populations. Bounding estimates, on the other hand, are constructed to be equal to or greater than the highest actual risk in the population (or the highest risk that could be expected in a future scenario). A "worst case scenario" refers to a combination of events and conditions such that, taken together, produces the highest conceivable risk. Although it is possible that such an exposure, dose, or sensitivity combination might occur in a given population of interest, the probability of an individual receiving this combination of events and conditions is usually small, and often so small that such a combination will not occur in a particular, actual population.

⁴ Maximizing all variables will in virtually all cases result in an estimate that is above the actual values seen in the population.

When the principal parameters of the dose equation, e.g., concentration (appropriately integrated over time), intake rate, duration, are broken out into subcomponents, it may be necessary to use maximum values for more than two of these subcomponent parameters, depending on a sensitivity analysis.

⁵ This holds true when variables are added (e.g., exposures by different routes) or when independent variables are multi (e.g., concentration x intake). However, it would be incorrect for products of correlated variables, variables used as divisors or for formulas involving exponents.

⁶ However, certain important cautions apply (see EPA's Exposure Assessment Guidelines). Also, this is not appropriate for non-carcinogenic effects or for other types of cancer models. For non-linear cancer models, an estimate of population risk must be calculated using the distribution of individual risks.

⁷ Some programs routinely develop future scenarios as part of developing a risk assessment. Program-specific guidance address future scenarios in more detail than they are described here.

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