A Life Stage Approach to Assessing Children's Exposures

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Background

Considering risks to infants and children as part of risk assessments are of primary importance to the U.S. Environmental Protection Agency (EPA). In 1995, EPA issued a policy for "Evaluating Health Risks to Children" (U.S. EPA, 1995), to ensure that risks to infants and children are consistently and explicitly a part of risk assessments conducted in support of the decision making process. Subsequently, the Food Quality Protection Act (FQPA) and the Safe Drinking Water Act Amendments of 1996 established provisions requiring the consideration of children in setting health standards (U.S. Congress 1996 a, b). In 1997, the President of the United States signed the Executive Order (E.O.) 13045, "Protection of Children from Environmental Health Risks and Safety Risks." This executive order states that "each Federal agency: (a) shall make it a high priority to identify and assess environmental health and safety risks that may disproportionately affect children; and (b) shall ensure that its policies, programs, activities, and standards address disproportionate risks to children that result from environmental health risks or safety risks" (E.O. 1997). These initial efforts provided the foundation for a series of initiatives within the EPA to address children's risks from environmental contaminants. For example, the Voluntary Children's Chemical Evaluation Program (VCCEP), initiated by EPA in 2000, is intended to provide data to enable the public to understand the potential health risks to children associated with certain chemical exposures. The EPA Draft Final Guidelines for Carcinogen Risk Assessment and the Supplemental Guidance for Assessing Cancer Susceptibility from Early-Life Exposure to Carcinogens explicitly call for consideration of possible susceptible subpopulations and/or life stages (such as childhood) (U.S. EPA 2003a, b). As another example, the proposed Utility Mercury Reductions Rule, published January 30, 2004, intends to reduce mercury emissions from oil- and coal-fired electric utility steam generating units. Because of its toxicity to developing cells, methylmercury and inorganic mercury are pollutants of concern for very young children and women of child-bearing age.

Exposures differ with developmental stage because the environments of fetuses, children, and adolescents are different than those of adults. On a body weight basis, children breathe more air, drink more water, and consume more of certain foods than adults (Moya et al, 2004). Patterns of exposure differ between children and adults. Children's activities and behaviors also put them at higher risk from environmental contaminants. Environmental health threats to children are often difficult to recognize and assess because of limited understanding of when and why children's exposures

and responses are different from those of adults. For children, behavior and physiology as a function of life stage may have a significant impact on exposure. The consideration of life stage specific periods of unique susceptibility in relation to childhood activities,behaviors, and intakes was recognized in the International Life Sciences Institute (ILSI) in the 2001 workshop (Olin and Sonawane 2002). The EPA's Office of Research and Development has focused on several efforts aimed at encouraging the use of this life stage approach to strengthen the scientific foundation of the EPA risk assessments and risk management decisions that affect children.

A Life Stage Approach

This paper discusses a comprehensive approach being developed to characterize children's exposures to environmental contaminants using a life stage framework for assessing children's exposure. This approach ensures a more complete evaluation of the potential for vulnerability and exposure of various populations throughout life. Life stages are defined as temporal stages (or intervals) of life that have distinct anatomical, physiological, behavioral and/or functional characteristics that contribute to potential differences in environmental exposures. Generally, risk assessments rely on available adult data and do not necessarily account for the lack of data at other life stages. The life stage approach in exposure assessments encourages a closer interaction between exposure and hazard characterization experts and uses data on critical windows of development for different organ systems and differences in anatomy, physiology and behavior that can impact external exposure and internal dose metrics.

In the past, there hasn't been a consistent way of defining age categories for children for the purposes of conducting exposure assessments. Children develop in spurts and, at times, discontinuously. For this reason, children's behavioral stages are better defined as a continuum rather than fixed age categories. Sometimes the categories selected have been driven by the amount of data available. EPA is, however, developing guidance to assist assessors in the selection of appropriate age groups for children's assessments. These age groups and their rationale are described in EPA's Draft Guidance on Selecting the Appropriate Age Groups for Assessing Childhood Exposures to Environmental Contaminants (U.S. EPA, 2003d).

The basic exposure framework includes several steps. The process begins with problem formulation and development of a conceptual model describing how relevant exposures may take place. This conceptual model provides the basis for conducting a detailed exposure assessment for children. Next, the conceptual model is used to identify required data and to review available exposure information. Finally, the exposure analysis and characterization are conducted and coordinated with the hazard and dose-response analyses.

Exposure Assessment Framework

Exposure Problem Formulation and Development of Conceptual Model

The problem formulation begins with planning and scoping to establish the goals, breadth, and focus of the assessment. This initial planning results in the development of a conceptual model which needs to consider important life stages. Within each life stage, there may be a series of developmental periods for which exposure needs to be characterized. These periods may be defined based on exposures that can

impact development (e.g., parental preconception exposures), or other potential windows of susceptibility identified through the hazard assessment (e.g., those during prenatal development), or windows of potentially high exposure due to age-specific behaviors and physiology (e.g., crawling, teething). Particular emphasis should be placed on identifying exposure sources in the places where children spend time; these may be distinct for each developmental stage. For example, sources may be identified in (1) residence and workplace for pregnant and lactating women; (2) residence, daycare and outdoor play areas for infants and toddlers; (3) residence, school, and locations of after-school activities for school-age children; and (4) residence, school, and locations of after-school activities and workplace for adolescents. In addition, depending on the risk assessment objectives, it may be important to involve the community in identifying sources of concern to community members.

For a given source, exposure media and exposure routes can define the pathways. Exposure media include cord blood and amniotic fluid, breast milk, air, water, soil/dust/sediments, food, and objects/surfaces, while exposure routes include trans-placental absorption, inhalation, ingestion, dermal absorption, and indirect ingestion (non-dietary and indirect dietary routes). The result of this evaluation would be a table in which potential exposure routes are identified for each exposure medium (direct and indirect). Exposure media may also change with life stage. For any given pathway, a set of associated exposure scenarios describes how an exposure takes place. This is needed to estimate the potential distribution of exposure by any given pathway.

Potential exposure scenarios of interest should be identified initially based on the conceptual exposure model as well as the problem formulation. For any given pathway, a set of associated exposure scenarios describes how an exposure takes place. Exposure scenarios need to be identified to specify the values of exposure factors. An exposure scenario is defined by a combination of information on sources, exposed population (e.g., age or developmental stage), time frame of exposure (e.g., acute, short term, chronic, intermittent), location of exposure (e.g., residence, school, outdoors, indoors), and activity (e.g., mouthing, playing soccer, mowing lawns) (Hubal, et al. 2000). Once available data are evaluated, additional scenarios may be identified.

Available Exposure Data for Assessments

Child-specific exposure data are needed to estimate distributions of exposure in the exposed population. Child-specific exposure data for U.S. populations are summarized in the U.S. EPA Child-Specific Exposure Factors Handbook. The handbook provides ranges and distributions of exposure factors data including: breast milk intake, tap water intake, food intake, soil intake, mouthing behavior, soil adherence, inhalation rates, time activity patterns, body weight, and life expectancy (U.S. EPA 2002). In addition, the EPA Consolidated Human Activity Database provides human activity information for U.S. populations on an activity-by-activity basis (McCurdy, 2000). Although these tools may be useful to other countries, some exposure factors may not be representatives of characteristics and behaviors of populations in other countries and other cultures.

Children are exposed to a variety of environmental contaminants. Pollutants that may affect children’s

health can be found in outdoor and indoor air, soil, food, and water. Measurements of these contaminants in each media are necessary to ensure that children are being protected from these environmental hazards. Common contaminants found in outdoor air include ground level ozone, particulate matter, sulfur dioxide, carbon monoxide, lead, and nitrogen dioxide. Sources of indoor air pollution include combustion sources such as gas stoves, fireplaces, and cigarettes; building materials such as treated wood and paints, furnishings, carpet, and fabrics; and consumer products such as sprays, pesticides, window cleaners, and laundry soap. Contaminants in drinking water come from a variety of sources including, for example, fertilizers, sewage, and livestock manures. Children may also be exposed to chemicals from pesticide residues in foods. Chemicals migrating from hazardous waste sites can contaminate soils from residential areas where children play. Data on levels and trends of environmental contaminants in air, soil, food, and water for children in the U.S. have been reported in EPA's report entitled America's Children and the Environment: Measures of Contaminants, Body Burdens and Illnesses (U. S. EPA 2003c).

Specific Considerations for Life Stages

Exposures are estimated depending on the purpose of the assessment. This may be accomplished in various tiers beginning with screening and moving towards a more refined assessment, if needed. Assessments of agents with multiple sources in their immediate environments are of particular interest for children. A complete exposure assessment for children will also require that those with potentially highest exposures, or significant exposures during critical windows of susceptibility, be identified. This requires that, even at the screening level, a large number of factors be collected and tracked, along with their associated variability and uncertainties.

There are three approaches that may be used to calculate exposures: the point-of-contact approach, the scenario evaluation approach, and the dose reconstruction approach. The approach used is determined by the type of data available and the scope of the assessment. The results of the assessment are then summarized and communicated to the risk manager in a clear and concise manner. An important issue associated with communicating results of an exposure assessment for children involves a characterization of uncertainty and variability. Uncertainty in the exposure estimates may be based on a lack of data for any of the significant exposure factors for a particular age group or with assumptions made in development of the model structure. With children, the issue of inter-subject variability can be important due to rapid physiological and behavioral changes such that even within a relatively narrow age group, variability may be particularly large. This variability affects our understanding of the upper percentiles of exposure and risk and so can be critical to children's risk assessment.

Conclusions

Children's activities and behaviors result in their having exposures from environmental contaminants that can be quite different from those of adults. Considering a life stage approach to assess exposure to children can ensure that important pathways of exposures and critical windows of susceptibility are considered. This comprehensive approach will improve our ability to assess exposure to children and will highlight important data gaps where future research can be focused.

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