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United States
Environmental Protection
Agency

Highlights of the Child-Specific Exposure Factors Handbook

National Center for Environmental Assessment
Office of Research and Development, Washington, DC 20460

EPA/600/R-08/135
August 2009
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U.S. Environmental Protection Agency
Washington, DC 20460

NOTICE

The U.S. Environmental Protection Agency through its Office of Research and Development, National Center for Environmental Assessment, funded the research described here under contract no. EP-W-04-035 with Versar, Inc. This document contains a brief overview of the contents of the 2008 version of the *Child-Specific Exposure Factors Handbook*, which was published earlier, i.e., 2002 and revised in 2005. This highlights document has been subjected to the Agency's administrative review and has been approved for publication as an EPA document.

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FOREWORD

In 2008, the U.S. Environmental Protection Agency (EPA), Office of Research and Development, National Center for Environmental Assessment (NCEA) published a revised version of its original 2002 *Child-Specific Exposure Factors Handbook*. Its purpose is to provide exposure/risk assessors with information on behavioral and physiological factors that can be used in assessing exposures among children. The Handbook presents information on children's exposure factors, based on selected studies published through July 2008. It uses a standard set of age categories for children, ages 0 to <21 years old, to permit comparison of data among multiple sources and to provide consistency among different types of exposure factors. The Handbook provides recommended values for the various exposure factors based on these standard age groups. These revisions assist exposure assessors with the implementation of the recommendations presented in the EPA's 2005 *Guidelines for Carcinogen Risk Assessment* and the *Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens.* Specifically, the 2005 Guidelines emphasized the need to consider childhood as a series of life stages rather than children as subpopulations and to sum exposures and risks across life stages rather than relying on the use of a lifetime average adult exposure to calculate risk.

The goals for revising the Handbook were to

(1) most importantly, reanalyze data and present the information using the standardized set of childhood age groups as recommended in EPA's 2005 *Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants*; and
(2) incorporate new exposure factors data/research that had become available since the early 2000s.

This Highlights document was developed to provide a brief overview of the contents of the *Child-Specific Exposure Factors Handbook* and to facilitate access to its exposure factors recommendations. As such, it contains a subset of the information provided in the complete Handbook. This Highlights document is a product of the EPA's Exposure Factors Program. NCEA established the Exposure Factors Program to develop tools and databases that improve the scientific basis of exposure and risk assessment by (1) identifying exposure factors needs in consultation with clients, and exploring ways for filling data gaps; (2) compiling existing data on exposure factors needed for assessing exposures/risks; and (3) assisting clients in the use of exposure factors data. These activities are supported by and respond to the needs of the various EPA program offices.

EPA invites you to visit http://epa.gov/risk/guidance.htm where you can view and download chapters from the *Child-Specific Exposure Factors Handbook* as well as the *Exposure Factors Handbook.* Each chapter in these handbooks presents recommended values for exposure factors as well as a discussion of the underlying data used to develop the recommendations. NCEA intends to update its Web site periodically so that the information provided by the Exposure Factors Program is current and relevant.

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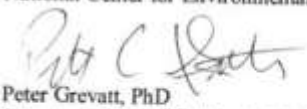

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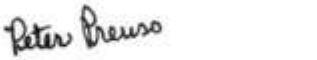

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ACRONYMS AND ABBREVIATIONS

ADAF	=	Age Dependent Adjustment Factors
ADD	=	Average Daily Dose
BMD	=	Benchmark Dose
C	=	Contaminant Concentration
cm^2	=	Square Centimeter
ED	=	Exposure Duration
g	=	Gram
GAF	=	General Assessment Factor
H_c	=	Human Equivalent Concentration
IR	=	Intake Rate
kg	=	Kilogram
LADD	=	Lifetime Average Daily Dose
m^2	=	Square Meter
m^3	=	Cubic Meter
mg	=	Milligram
mL	=	Milliliter
NCEA	=	National Center for Environmental Assessment
OCHP	=	Office of Children's Health Protection
OCHPEE	=	Office of Children's Health Protection and Environmental Education
ORD	=	Office of Research and Development
PBPK	=	Physiologically-Based Pharmacokinetic
RfD	=	Reference Dose
RfC	=	Reference Concentration
SPC	=	Science Policy Council
USDA	=	United States Department of Agriculture
U.S. EPA	=	U.S. Environmental Protection Agency

ABOUT THE HANDBOOK

This Highlights document presents an overview of the information provided in the U.S. EPA's *Child-Specific Exposure Factors Handbook* (U.S. EPA 2008a). The Handbook reviews and summarizes data on the various factors used in the exposure assessment of children (i.e., individuals <21 years old) and provides recommendations for the exposure assessment community. The Handbook contains 17 chapters: an introduction (Chapter 1), a discussion about the variability and uncertainty in assessing exposure factors (Chapter 2), and nonchemical-specific data on exposure factors for the U.S. EPA recommended set of childhood age groups in the following areas:

- ingestion of water and other select liquids (Chapter 3);
- non-dietary ingestion factors (Chapter 4);
- ingestion of soil and dust (Chapter 5);
- inhalation rates (Chapter 6);
- dermal exposure factors (Chapter 7);
- body weight (Chapter 8);
- intake of fruits and vegetables (Chapter 9);
- intake of fish and shellfish (Chapter 10);
- intake of meat, dairy products, and fats (Chapter 11);
- intake of grain products (Chapter 12);
- intake of home-produced foods (Chapter 13);
- total food intake (Chapter 14);
- human milk intake (Chapter 15);
- activity factors (Chapter 16); and
- consumer products (Chapter 17).

The *Child-Specific Exposure Factors Handbook* was first published in 2002 (U.S. EPA, 2002a). Subsequently, the U.S. EPA published its *Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants* (U.S. EPA, 2005a). To the extent possible, source data for the independent studies cited in the earlier version of the Handbook were obtained and reanalyzed to conform to the standard age categories: birth to <1 month, 1 to <3 months, 3 to <6 months, 6 to <12 months, 1 to <2 years, 2 to <3 years, 3 to <6 years, 6 to <11 years, 11 to <16 years, and 16 to <21 years.

The data presented in the *Child-Specific Exposure Factors Handbook* were compiled from various sources including the U.S. EPA's *Exposure Factors Handbook* (U.S. EPA, 1997a), government reports, and information presented in the scientific literature, published through July 2008. The data presented are generally the result of analyses by the individual study authors. However, in some cases, the U.S. EPA conducted analysis of published primary data to present results for the recommended age groups. Studies presented in the Handbook were chosen because they were seen as useful and appropriate for estimating exposure factors based on the following evaluation elements: (1) soundness; (2) applicability and utility; (3) clarity and completeness; (4) variability and uncertainty; and (5) evaluation and review.

Generally, studies were designated as "key" or "relevant" studies. Key studies were considered the most useful for deriving recommendations, while relevant studies provided applicable or pertinent data, but not necessarily the most important for a variety of reasons (e.g., data were outdated, limitations in study design). The Handbook provides recommended values for exposure factors based on its interpretation of the key studies. Key recommendations from the Handbook are summarized in Table 1 (see pages 17-24) of this Highlights document. Additional recommendations and detailed supporting information can be found in the individual chapters of the Handbook. These recommendations are not legally binding and should be interpreted as suggestions that U.S. EPA Program Offices or individual exposure/risk assessors can consider and modify as needed based on their own evaluation of a given risk-assessment situation. In certain cases, different values may be appropriate in consideration of policy, precedent, strategy, or other factors (e.g., more up-to-date data of better quality or more representative of the population of concern). The U.S. EPA also assigned confidence ratings of *low, medium, or high* to each recommended value based on the evaluation elements described above. These ratings are not intended to represent uncertainty

analyses; rather, they represent the U.S. EPA's judgment on the quality of the underlying data used to derive the recommendations.

All tables and figures have been placed at the end of the Handbook.

INTENDED AUDIENCE

The *Child-Specific Exposure Factors Handbook* (U.S. EPA 2008a) is intended for use by exposure and risk assessors both within and outside the U.S. EPA as a reference tool and primary source of exposure factor information. It may be used by exposure and risk assessors, economists, and other interested parties as a source for data and/or U.S. EPA recommendations on numeric estimates for behavioral and physiological characteristics needed to estimate childhood exposure to toxic contaminants and other environmental stressors.

BACKGROUND

Because of physiological and behavioral differences, environmental exposures among children differ from exposures among adults. Children may be more exposed to some environmental contaminants because (1) they consume more of certain foods and water per unit of body weight than adults; (2) they have a higher ratio of body surface area to volume than adults; and (3) they experience important, rapid changes in behavior and physiology that may lead to differences in exposure. Many studies have shown that young children can be exposed to various contaminants, including pesticides, during normal oral exploration of their environment (i.e., hand-to-mouth behavior) and by touching floors, surfaces, and objects such as toys (Eskenazi et al., 1999; Gurunathan et al., 1998; Lewis et al., 1999; Nishioka et al., 1999; Garry, 2004). Dust and tracked-in soil accumulate in carpets, where young children spend a significant amount of time (Lewis et al., 1999). Children living in agricultural areas may experience higher exposures to pesticides than do other children (Curwin et al., 2007). They may play in nearby fields or be exposed via consumption of contaminated human milk from their farmworker mothers (Eskenazi et al., 1999).

In terms of risk, children may also differ from adults in their vulnerability to environmental pollutants because of toxicodynamic differences (e.g., when exposures occur during periods of enhanced susceptibility) and/or toxicokinetic differences (i.e., differences in absorption, metabolism, and excretion) (U.S. EPA, 2000a). The immaturity of metabolic enzyme systems and clearance mechanisms in young children can result in longer half-lives of environmental contaminants (Ginsberg et al., 2002; Clewell et al., 2004). The cellular immaturity of children and the ongoing growth processes account for elevated risk (AAP, 1997). Toxic chemicals in the environment can cause neurodevelopmental disabilities, and the developing brain can be particularly sensitive to environmental contaminants. For example, elevated blood lead levels and prenatal exposures to even relatively low levels of lead can result in behavior disorders and reductions of intellectual function in children (Landrigan et al., 2005). Exposure to high levels of methylmercury can result in developmental disabilities (e.g., intellectual deficiency, speech disorders, and sensory disturbances) among children (Myers et al., 2000). Other authors have described the importance of exposure timing (i.e., preconceptional, prenatal, and postnatal) and how it affects the outcomes observed (Selevan et al., 2000). It has also been suggested that higher levels of exposure to indoor air pollution and allergens among inner-city children compared to non-inner-city children may explain the difference in asthma levels between these two groups (Breysee et al., 2005). With respect to contaminants that are carcinogenic via a mutagenic mode of action, the U.S. EPA has found that childhood is a particularly sensitive period of development in which cancer potencies per year of exposure can be an order of magnitude higher than during adulthood (U.S. EPA, 2005c).

Executive Order 13045: *Protection of Children from Environmental Health Risks and Safety Risks*, signed in 1997, requires all federal agencies to address health and safety risks to children, to coordinate research priorities on children's health, and to ensure that their standards take into account special risks to children (EO, 1997). To implement the Order, the U.S. EPA established the Office of Children's Health Protection (OCHP) (renamed the Office of Children's Health Protection and Environmental Education [OCHPEE] in 2005), who works with Program and regional offices within the U.S. EPA to promote a safe and healthy environment for children by ensuring that all regulations, standards, policies, and risk assessments take into account risks to children. Legislation, such as the Food Quality Protection Act and the Safe Drinking Water Act amendments of 1996, has made coverage

of children's health issues more explicit, and research on children's health issues is continually expanding. As a result of the emphasis on children's risk, the U.S. EPA's ORD developed a *Strategy for Research on Environmental Risks to Children* (U.S. EPA, 2000a). The goal of the Strategy is to improve the quality of risk assessments for children. The *Child-Specific Exposure Factors Handbook* (U.S. EPA, 2008a) is intended to support the U.S. EPA/ORD's efforts to improve exposure and risk assessments for children.

In 1997, the U.S. EPA/ORD/NCEA published the *Exposure Factors Handbook* (U.S. EPA, 1997a). The Handbook includes exposure factors and related data on both adults and children. Subsequently, the U.S. EPA Program Offices identified the need to consolidate all children's exposure data into a single document, and the interim final *Child-Specific Exposure Factors Handbook* was published in 2002 to fulfill this need (U.S. EPA, 2002a). The 2008 Handbook (U.S. EPA, 2008a) updates the 2002 edition of the *Child-Specific Exposure Factors Handbook*. It provides nonchemical-specific data on exposure factors that can be used to assess contributions from dietary and non-dietary ingestion exposure, dermal exposure, and inhalation exposure among children. Although the preconceptional and prenatal (fetal) life stages are important to consider, they are not covered in the Handbook. Preconceptional exposures are included in the *Exposure Factors Handbook* (U.S. EPA, 1997a) since they relate to maternal and paternal exposures, and exposure factors for pregnant and lactating women are being developed as part of a separate effort. The Handbook also highlights the changes in risk-assessment practices that were first presented in the U.S. EPA's Cancer Guidelines (U.S. EPA, 2005b), regarding the need to consider children as life stages rather than as subpopulations. It also emphasizes a major recommendation in U.S. EPA's *Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens* (U.S. EPA, 2005c) to sum exposures and risks across life stages rather than relying on the use of a lifetime average adult exposure to calculate risk.

The *Child-Specific Exposure Factors Handbook* (U.S. EPA, 2008a) does not include chemical-specific data or information on physiological parameters that may be needed for exposure assessments involving physiologically-based pharmacokinetic (PBPK) modeling. The U.S. EPA has developed guidance on how to use and applications of PBPK information in risk assessment in the report titled *Use of Physiologically Based Pharmacokinetic (PBPK) Models to Quantify the Impact of Human Age and Interindividual Differences in Physiology and Biochemistry Pertinent to Risk* (U.S. EPA, 2006a).

With very few exceptions, the data presented in the Handbook were derived from the analyses of the individual study authors. Because the studies included in the Handbook vary in terms of their objectives, design, scope, presentation of results, etc., the level of detail, statistics, and terminology may vary from study to study and from factor to factor. For example, some authors used geometric means to present their results, while others used arithmetic means or distributions. Authors sometimes used different age ranges to describe data for children. In most cases, the original data were unavailable, and the study results could not be reallocated into the standard age groups used in the Handbook. When adequate detailed data were available, efforts were made to reallocate source data into the standard age groups recommended by the U.S. EPA in the report titled *Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants* (U.S. EPA, 2005a). Within the constraint of presenting the original material as accurately as possible, the U.S. EPA made an effort to present discussions and results in a consistent manner. The strengths and limitations of each study were discussed to provide the reader with a better understanding of the uncertainties associated with the values derived from the study.

Most of the data presented in the Handbook were derived from studies that targeted (1) the general national population (e.g., USDA food consumption surveys) or (2) a sample population from a specific area or group (e.g., soil ingestion in children from a three-city area in southeastern Washington State). If it is necessary to characterize a population that is not directly covered by the data in the Handbook, the risk or exposure assessor should evaluate whether these data may be used as suitable substitutes for the population of interest or whether there is a need to seek additional population-specific data. The decision as to whether to use site-specific or national

values for an assessment depends both on the quality of the competing data sets as well as on the purpose of the specific assessment. If information is needed for identifying and enumerating populations who may be at risk for greater contaminant exposures or who exhibit a heightened sensitivity to particular chemicals, the reader is referred to *Socio-demographic Data Used for Identifying Potentially Highly Exposed Populations* (U.S. EPA, 1999).

In conjunction with the *Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants* (U.S. EPA, 2005a), the Handbook adopted the age group notation "X to < Y" (e.g., the age group 3 to <6 years is meant to span a 3-year time interval from a child's 3rd birthday up until the day before his or her 6th birthday).

SELECTION OF STUDIES FOR THE HANDBOOK

Information in the Handbook was summarized from studies documented in the scientific literature and other available sources. Studies were chosen that were seen as useful and appropriate for estimating exposure factors for children. The Handbook contains summaries of selected studies published through July 2008.

Certain studies described in the Handbook are designated as "key," that is, the most useful for deriving exposure factors. The recommended values for most exposure factors are based on the results of the key studies. Other studies are designated "relevant," meaning applicable or pertinent, but not necessarily the most important. This distinction was made on the strength of the attributes listed in the "General Assessment Factors" listed below.

General Assessment Factors

The U.S. EPA recognizes the need to evaluate the quality and relevance of scientific and technical information used in support of Agency actions (U.S. EPA, 2002b, 2003a, 2006b). When evaluating scientific and technical information, the U.S. EPA's Science Policy Council (SPC) recommends using five General Assessment Factors (GAFs): (1) soundness, (2) applicability and utility, (3) clarity and completeness, (4) uncertainty and variability, and (5) evaluation and review (U.S. EPA, 2003a). These GAFs were adapted and expanded to include specific considerations deemed to be important during evaluation of exposure factors data, and were used to judge the quality of the underlying data used to derive recommendations.

Selection Criteria

The selection of key studies that form the basis for the exposure factor recommendations provided in the *Child-Specific Exposure Factors Handbook* (U.S. EPA, 2008a) as well as the confidence ratings for these recommendations, were based on specific criteria within each of the five GAFs, as follows:

(1) Soundness: *Scientific and technical procedures, measures, methods, or models employed to generate the information are reasonable for, and consistent with, the intended application*.

Adequacy of the Study Approach: In general, more confidence was placed on experimental procedures or approaches that more likely or closely captured the desired measurement. Direct exposure data collection techniques, such as direct observation, personal monitoring devices, or other known methods were preferred where available. If studies utilizing direct measurement were not available, studies were selected that relied on validated indirect measurement methods. Studies were also deemed preferable if based on primary data, but studies based on secondary sources were also included where they offered an original analysis. In general, higher confidence was placed on exposure factors based on primary data.

Minimal (or Defined) Bias in Study Design: More confidence was placed on exposure factors based on studies that minimized bias. Studies were sought that were designed with minimal bias, or at least if biases were suspected to be present, the direction of the bias (i.e., an over or underestimate of the parameter) was either stated or apparent from the study design.

(2) Applicability and Utility: *The information is relevant for the Agency's intended use.*

Focus on Exposure Factor of Interest: Studies were preferred that directly addressed the exposure factor of interest, or addressed related factors that have significance for the factor under consideration.

Representativeness of the Population: More confidence was placed in studies that specifically addressed the United States population. Data from populations outside the United States were sometimes included if behavioral patterns or other characteristics of exposure were similar. Additionally, studies seeking to characterize a particular region or population were selected, if appropriately representative of that population.

Currency of Information: More confidence was placed in studies that were sufficiently recent to represent current exposure conditions. This is an important consideration for those factors that change with time. Older data were evaluated and considered in instances where the variability of the exposure factor over time was determined to be insignificant or unimportant. In some cases, recent data were very limited. Therefore, the data provided in these instances were the only available data. Limitations on the age of the data were noted. Recent studies are more likely to use state-of-the-science methodologies that reflect advances in the exposure assessment field. Consequently, exposure factor recommendations based on current data were given higher confidence ratings than those based on older data—except in cases where the age of the data would not affect the recommended values.

Adequacy of Data Collection Period: Because most users of the Handbook are primarily addressing chronic exposures, studies were sought that utilized the most appropriate techniques for collecting data to characterize long-term behavior. Higher confidence ratings were given to exposure factor recommendations that were based on an adequate data collection period.

(3) Clarity and Completeness: *The degree of clarity and completeness with which the data, assumptions, methods, quality assurance, sponsoring organizations, and analyses employed to generate the information are documented*.

Accessibility: Studies that the user could access in their entirety, if needed, were preferred.

Reproducibility: Studies that contained sufficient information so that methods could be reproduced, or could be evaluated, based on the details of the author's work, were preferred.

Quality Assurance: Studies with documented quality-assurance/quality-control measures were preferred. Higher confidence ratings were given to exposure factors that were based on studies where appropriate quality assurance/quality control measures were used.

(4) Variability and Uncertainty: *The variability and uncertainty (quantitative and qualitative) in the information or the procedures, measures, methods, or models are evaluated and characterized.*

Variability in the Population: Variability arises from true heterogeneity across people, places, or time and can affect the precision of exposure estimates and the degree to which they can be generalized. The types of variability include spatial, temporal, and interindividual. Studies were sought that characterized any variability within populations. Higher confidence ratings were given to exposure factors that were based on studies where variability was well characterized.

Uncertainty: Uncertainty represents a lack of knowledge about factors affecting exposure or risk and can lead to inaccurate or biased estimates of exposure. The types of uncertainty include scenario, parameter, and model. Studies were sought with minimal uncertainty in the data, which was judged by evaluating all the considerations listed above.

Studies were preferred that identified uncertainties, such as those due to inherent variability in environmental and exposure-related parameters or possible measurement error. Higher confidence ratings were given to exposure factors based on studies where uncertainty had been minimized.

(5) Evaluation and Review: *The information or the procedures, measures, methods, or models are independently verified, validated, and peer reviewed.*

Peer Review: Studies selected were those from the peer-reviewed literature and final government reports. Unpublished and internal or interim reports were avoided.

Number and Agreement of Studies: Higher confidence was placed on recommendations where data were available from more than one key study and there was good agreement between studies.

APPROACH USED TO DEVELOP RECOMMENDATIONS FOR EXPOSURE FACTORS

As a first step to develop recommendations, the U.S. EPA reviewed the literature pertaining to a factor and determined key studies. These key studies were used to derive recommendations for the values of each factor. The recommended values were derived solely from the U.S. EPA's interpretation of the available data. Different values may be appropriate for the user in consideration of policy, precedent, strategy, or other factors such as site-specific information.

In providing recommendations for the various exposure factors, an attempt was made to present percentile values that are consistent with the exposure estimators defined in *Guidelines for Exposure Assessment* (i.e., mean, 50th, 90th, 95th, 98th, and 99.9th percentiles) (U.S. EPA. 1992a). However, this was not always possible because the data available were limited for some factors, or the study authors did not provide such information. It is important to note, however, that these percentiles were discussed in the Guidelines within the context of risk descriptors and not individual exposure factors. For example, the guidelines state that the assessor may derive a high-end estimate of exposure by using maximum or near maximum values for one or more sensitive exposure factors, leaving others at their mean value. The term "upper percentile" is used throughout the Handbook, and it is intended to represent values in the upper tail (i.e., between 90th and 99.9th percentiles) of the distribution of values for a particular exposure factor.

The U.S. EPA's procedure for developing recommendations was as follows:

(1) Study Review and Evaluation: Key studies were evaluated in terms of both quality and relevance to specific populations (general U.S. population, age groups, gender, etc.). The GAFs described earlier were used as criteria for assessing the quality of studies.

(2) Single Versus Multiple Key Studies: If only one study was classified as key for a particular factor, the mean value from that study was selected as the recommended central value for that population. If multiple key studies with reasonably equal quality, relevance, and study design information were available, a weighted mean (if appropriate, considering sample size and other statistical factors) of the studies was chosen as the recommended mean value. If the key studies were judged to be unequal in quality, relevance, or study design, the range of means was presented, and the user of the Handbook must employ judgment in selecting the most appropriate value for the population of interest. Recommendations for upper percentiles, when multiple studies were available, were calculated as the midpoint of the range of upper percentile values of the studies for each age group where data were available.

(3) Variability: The variability of the factor across the population was described. For recommended values, as well as for each of the studies on which the recommendations are based, variability was characterized in one or more of three ways: (1) as a table with various percentiles or ranges of values; (2) as analytical distributions with specified parameters; and/or (3) as a qualitative discussion. Analyses to fit standard or parametric distributions (e.g., normal, lognormal)

to the exposure data were not performed by the authors of the Handbook, but they have been reproduced as they were found in the literature. Recommendations on the use of these distributions were made where appropriate based on the adequacy of the supporting data. The list of exposure factors and the way in which variability was characterized throughout the Handbook (i.e., average, median, upper percentiles, multiple percentiles, and fitted distribution) are presented in Table 2.

(4) Uncertainty: Uncertainties were discussed in terms of data limitations. Such limitations include the range of circumstances over which the estimates were (or were not) applicable, possible biases in the values themselves, a statement about parameter uncertainties (measurement error, sampling error) and model/scenario uncertainties, if models/scenarios were used to derive the recommended value. Chapter 2 of the Handbook presents a discussion of variability and uncertainty for exposure factors.

(5) Confidence Ratings: Finally, the U.S. EPA assigned a confidence rating of *low, medium, or high* to each recommended value. This rating is not intended to represent an uncertainty analysis; rather, it represents the U.S. EPA's judgment on the quality of the underlying data used to derive the recommendation. This judgment was made using the GAFs described earlier. Table 3 provides an adaptation of the GAFs as they pertain to the confidence ratings for the exposure factor recommendations. Clearly, there is a continuum from *low to high.* Therefore, the assignment of a rating to a particular factor involves professional judgment. Recommendations given in the Handbook are accompanied by a discussion of the rationale for their rating.

It is important to note that the study elements listed in Table 3 do not have the same weight when arriving at the overall confidence rating for the various exposure factors. The relative weight of each of these elements for the various factors is subjective and based on the professional judgment of the authors of the Handbook. Also, the relative weights depend on the exposure factor of interest. For example, the adequacy of the data collection period may be more important when determining usual intake of foods in a population, but it is not as important for factors where long-term variability may be small, such as tap water intake. In the case of tap water intake, the currency of the data was a critical element in determining the final rating. In general, most studies ranked high with regard to "level of peer review," "accessibility," "focus on the factor of interest," and "data pertinent to the United States" because the U.S. EPA specifically sought studies for the Handbook that met these criteria.

The elements in Table 3 were important considerations for inclusion of a study in the Handbook. However, a high score for these elements does not necessarily translate into a high overall rating. Other considerations also informed the assigned confidence ratings. One such consideration was the ease at which the exposure factor of interest could be measured. For example, soil ingestion by children can be estimated by measuring, in the feces of children, the levels of certain elements found in soil. Body weight, however, can be measured directly, and it is therefore a more reliable measurement. The fact that soil ingestion is more difficult to measure than body weight is reflected in the overall confidence rating given to both of these factors. In general, the better the methodology used to measure the exposure factor, the higher the confidence in the value.

(6) Recommendation Tables: The U.S. EPA developed a table at the beginning of each chapter of the *Child-Specific Exposure Factors Handbook* (U.S. EPA, 2008a) that summarizes the recommended values for the relevant factor. Table 1 summarizes the principal exposure factors addressed in the Handbook. Table 4 summarizes the confidence ratings assigned to the various factors.

SUGGESTED REFERENCES FOR USE IN CONJUNCTION WITH THE HANDBOOK

The main steps for performing an exposure assessment are (1) identifying the source of the

environmental contamination and the media that transports the contaminant; (2) determining the contaminant concentration; (3) determining the exposure scenarios—including pathways and routes of exposure; (4) determining the exposure time, frequency, and duration; and (5) identifying the exposed population. Many of the issues related to characterizing exposure from selected exposure pathways have been addressed in a number of existing U.S. EPA documents. Some of these provide guidance while others demonstrate various aspects of the exposure process. These documents include, but are not limited, to the following, which are listed in chronological order:

- *Methods for Assessing Exposure to Chemical Substances, Volumes 1−13* (U.S. EPA, 1983−1989)
- *Standard Scenarios for Estimating Exposure to Chemical Substances During Use of Consumer Products* (U.S. EPA, 1986)
- *Selection Criteria for Mathematical Models Used in Exposure Assessments: Surface Water Models* (U.S. EPA, 1987)
- *Selection Criteria for Mathematical Models Used in Exposure Assessments: Groundwater Models* (U.S. EPA,1988)
- *Risk Assessment Guidance for Superfund, Volume I, Part A, Human Health Evaluation Manual* (U.S. EPA, 1989)
- *Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions* (U.S. EPA, 1990)
- *Risk Assessment Guidance for Superfund, Volume I, Part B, Development of Preliminary Remediation Goals* (U.S. EPA, 1991a)
- *Risk Assessment Guidance for Superfund, Volume I, Part C, Risk Evaluation of Remedial Alternatives* (U.S. EPA, 1991b)
- *Guidelines for Exposure Assessment* (U.S. EPA, 1992a)
- *Dermal Exposure Assessment: Principles and Applications* (U.S. EPA, 1992b)
- *Estimating Exposures to Dioxin-Like Compounds* (U.S. EPA, 1994a)
- *Soil Screening Guidance* (U.S. EPA, 1996a)
- *Series 875 Occupational and Residential Exposure Test Guidelines - Final Guidelines - Group A - Application Exposure Monitoring Test Guidelines* (U.S. EPA, 1996b)
- *Series 875 Occupational and Residential Exposure Test Guidelines - Group B - Post Application Exposure Monitoring Test Guidelines* (U.S. EPA, 1996c)
- *Policy for Use of Probabilistic Analysis in Risk Assessment at the U.S. Environmental Protection Agency* (U.S. EPA, 1997b)
- *Guiding Principles for Monte Carlo Analysis* (U.S. EPA, 1997c)
- *Sociodemographic Data for Identifying Potentially Highly Exposed Populations* (U.S. EPA, 1999)
- *Options for Developing Parametric Probability Distributions for Exposure Factors* (U.S. EPA, 2000b)
- *Risk Assessment Guidance for Superfund, Volume I, Part D, Standardized Planning, Reporting, and Review of Superfund Risk Assessments* (U.S. EPA, 2001a)
- *Risk Assessment Guidance for Superfund Volume III, Part A, Process for Conducting Probabilistic Risk Assessments* (U.S. EPA, 2001b)
- *Framework for Cumulative Risk Assessment* (U.S. EPA, 2003b)
- *Example Exposure Scenarios* (U.S. EPA, 2003c);
- *Risk Assessment Guidance for Superfund, Volume I, Part E, Supplemental Guidance for Dermal Risk Assessment* (U.S. EPA, 2004)
- *Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants* (U.S. EPA, 2005a)
- *Cancer Guidelines for Carcinogen Risk Assessment, Supplemental Guidance for*

Assessing Susceptibility from Early-Life Exposure to Carcinogens (U.S. EPA, 2005b)

- *Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens* (U.S. EPA, 2005c)
- *Protocol for Human Health Risk Assessment, Protocol for Hazardous Waste Combustion Facilities* (U.S. EPA, 2005d)
- *A Framework for Assessing Health Risk of Environmental Exposures to Children* (Final) (U.S. EPA, 2006c)
- *Concepts, Methods, and Data Sources for Cumulative Health Risk assessment of Multiple Chemicals, Exposures and Effects: A Resource Document* (Final) (U.S. EPA, 2008b)

These documents may serve as valuable information resources to assist in the assessment of exposure. The reader is encouraged to refer to them for more detailed discussion.

CONSIDERING LIFESTAGE WHEN CALCULATING EXPOSURE AND RISK

A key component of U.S. EPA's *Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants* (U.S. EPA, 2005a) involves the need to sum age-specific differences in exposure across time when assessing long-term exposure, as well as integrating these age-specific exposures with age-specific differences in toxic potency in those cases where information exists to describe such differences: an example is carcinogens that act via a mutagenic mode of action (*Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens* [U.S. EPA, 2005c]). When assessing chronic risks (i.e., exposures greater than 10% of human lifespan), rather than assuming a constant level of exposure for 70 years (usually consistent with an adult level of exposure), the Agency is now recommending that assessors calculate chronic exposures by summing time-weighted exposures that occur at each life stage; the Handbook provides data arrayed by childhood age in order to follow this new guidance. This approach is expected to increase the accuracy of risk assessments because it will account for life-stage differences in exposure. Depending on whether body-weight-adjusted childhood exposures are either smaller or larger compared to those for adults, calculated risks could either decrease or increase when compared with the historical approach of assuming a lifetime of a constant adult level of exposure.

The *Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens* also recommends that in those cases where age-related differences in toxicity also occur, differences in both toxicity and exposure should be integrated across all relevant age intervals. This guidance describes such a case for carcinogens that act via a mutagenic mode of action, where age dependent potency adjustments factors (ADAFs) of 10× and 3× are recommended for children ages birth to <2 years and 2 to <16 years, respectively, when there is exposure during those years and available data are insufficient to derive chemical-specific adjustment factors.

Table 5, along with Chapter 6 of the *Supplemental Guidance*, has been developed to help the reader understand how to use the new sets of exposure and potency age groupings when calculating risk through the integration of life-stage-specific changes in exposure and potency.

Thus, Lifetime Cancer Risk (for a population with average life expectancy of 70 years) = Σ (Exposure × Duration/70 yrs × Potency × ADAF) summed across all the age groups presented in Table 5. This is a departure from the way cancer risks have historically been calculated which was based upon the premise that risk is proportional to the daily average of the long-term adult dose.

FUNDAMENTAL PRINCIPLES OF EXPOSURE ASSESSMENT

The definition of *exposure* as used by the International Programme on Chemical Safety is the "contact of an organism with a chemical or physical agent, quantified as the amount of chemical available at the exchange boundaries of the organism and available for absorption." This means contact with the visible exterior of a person such as the skin, and openings such as orifices and lesions. The process of a chemical entering the body can be described in two steps: **contact** (exposure) followed by **entry** (crossing the boundary). In the context of

environmental risk assessment, risk to an individual or population can be represented as a continuum from the source through exposure to dose to effect as shown in Figure 1 (U.S. EPA, 2003d; IPCS, 2006). The process begins with a chemical or agent released from a source into the environment. Once in the environment, the chemical or agent can be transformed and transported through the environment via air, water, soil, dust, and diet. Individuals come in contact with the chemical through inhalation, ingestion, or skin/eye contact. The individual's activity patterns as well as the concentration of the chemical will determine the magnitude, frequency, and duration of the exposure. The exposure becomes an absorbed dose when the chemical crosses an absorption barrier. When the chemical or its metabolites interact with a target tissue, it becomes a target tissue dose, which may lead to an adverse health outcome. The text under the boxes in Figure 1 indicates the specific information that may be needed to characterize each box.

Dose Equations

Starting with a general integral equation for exposure (U.S. EPA, 1992a), several dose equations can be derived depending upon boundary assumptions. One of the more useful of these derived equations is the Average Daily Dose (ADD). The ADD, which is used for many noncancer effects, averages an external dose over the period of time exposure occurred, and it is normalized by body weight (ADD_{pot})(see equation 1).

$$ADD_{pot} = \frac{\text{External Dose}}{\text{Body Weight} \times \text{Averaging Time}} \quad (1)$$

The exposure can be expressed in as follows:

$$\text{External Dose} = C \times IR \times ED \quad (2)$$

Where

C = Contaminant Concentration
IR = Intake Rate
ED = Exposure Duration

Contaminant concentration is the concentration of the contaminant in the medium (e.g., air, food, and soil) contacting the body and has units of mass/volume or mass/mass.

The *intake rate* refers to the rates of inhalation, ingestion, and dermal contact, depending on the route of exposure. For ingestion, the intake rate is simply the amount of food containing the contaminant of interest that an individual ingests during some specific time period (units of mass/time). Much of the Handbook is devoted to rates of ingestion for some broad classes of food. For inhalation, the intake rate is the rate at which contaminated air is inhaled. Factors presented in the Handbook that affect dermal exposure are skin surface area and estimates of the amount of soil that adheres to the skin.

The *exposure duration* is the length of time of contaminant contact. The length of time a person lives in an area, frequency of bathing, time spent indoors versus outdoors, etc., all affect the exposure duration. Chapter 16, Activity Factors, describes examples of population behavior/activity patterns that may be useful for estimating exposure durations.

When the parameter values IR and ED remain constant over time, they are substituted directly into the exposure equation. When they change with time, a summation approach is needed to calculate exposure. In either case, the exposure duration is the length of time exposure occurs at the concentration and the intake rate specified by the other parameters in the equation.

Note that the advent of childhood age groupings means that separate ADDs should be calculated for each age group considered. Chronic exposures can then be calculated by summing across each life-stage-specific ADD.

Cancer risks have traditionally been calculated in those cases where a linear nonthreshold model is assumed, in terms of lifetime probabilities, by utilizing dose values presented in terms of lifetime ADDs (LADDs). The LADD takes the form of Equation 1, with lifetime replacing averaging time. While the use of LADD may be appropriate when developing screening level estimates of cancer risk, as discussed above, the U.S. EPA is now recommending that risks should be calculated by integrating exposures or risks throughout all life stages (U.S. EPA, 1992a).

For some types of analyses, dose can be expressed as a total amount (with units of mass, e.g., mg) or as a dose rate in terms of mass/time (e.g., mg/day), or as a rate normalized to body mass (e.g., with units of mg of chemical per kg of body weight

per day [mg/kg-day]). The LADD is usually expressed in terms of mg/kg-day or other mass/mass-time units.

In most cases (inhalation and ingestion exposures), the dose-response parameters for carcinogenic risks have been adjusted for the difference in absorption across body barriers between humans and the experimental animals used to derive such parameters. Therefore, the exposure assessment in these cases is based on the potential dose, with no explicit correction for the fraction absorbed. However, the exposure assessor needs to make such an adjustment when calculating dermal exposure and in other specific cases when current information indicates that the human absorption factor used in the derivation of the dose-response factor is inappropriate.

For carcinogens, the duration of a lifetime has traditionally been assigned the nominal value of 70 years as a reasonable approximation. For exposure estimates to be used for assessments other than carcinogenic risk, various averaging periods have been used. For acute exposures, the doses are usually averaged over a day or a single event. For nonchronic noncancer effects, the time period used is the actual period of exposure (exposure duration). The objective in selecting the exposure averaging time is to express the exposure in a way that can be combined with the dose-response relationship to calculate risk.

The body weight to be used in the exposure equation (see Equation 1) depends on the units of the exposure data presented in the Handbook. For example, for food ingestion, the body weights of the surveyed populations were known in the USDA surveys, and they were explicitly factored into the food intake data in order to calculate the intake as g/kg body weight-day. In this case, the body weight has already been included in the "intake rate" term in Equations 1–2, and the exposure assessor does not need to explicitly include body weight.

The units of intake in the Handbook for the incidental ingestion of soil and dust are not normalized to body weight. In this case, the exposure assessor will need to use the average weight of the exposed population during the time when the exposure actually occurs (shown in Equation 1). When making body weight assumptions, care must be taken that the values used for the population parameters in the dose-response analysis are consistent with the population parameters used in the exposure analysis. Intraspecies adjustments based on lifestage can be made using a scaling factor of $BW^{3/4}$ (U.S. EPA, 2006c; 2006d). Some of the parameters (primarily concentrations) used in estimating exposure are exclusively site specific, and, therefore, default recommendations should not be used. It should be noted that body weight is correlated with food consumption rates and inhalation rates.

The link between the intake rate value and the exposure duration value is a common source of confusion in defining exposure scenarios. It is important to define the duration estimate so that it is consistent with the intake rate:

- The intake rate can be based on an individual event (e.g., serving size per event). The duration should be based on the number of events or, in this case, meals.

- The intake rate also can be based on a long-term average, such as 10 g/day. In this case, the duration should be based on the total time interval over which the exposure occurs.

The objective is to define the terms so that, when multiplied, they give the appropriate estimate of mass of contaminant contacted. This can be accomplished by basing the intake rate on either a long-term average (chronic exposure) or an event (acute exposure) basis, as long as the duration value is selected appropriately.

Inhalation dosimetry is employed to derive the human equivalent concentration (H_c) on which inhalation unit risks, and reference concentrations, are based (U.S. EPA, 1994b). U.S. EPA has traditionally approximated children's respiratory exposure by using adult values, although a recent review (Ginsberg et al., 2002) concluded that there may be some cases where young children's greater inhalation rate per body weight or pulmonary surface area as compared to adults can result in greater exposures than adults. The implications of this difference for inhalation dosimetry and children's risk assessment were discussed at a peer involvement workshop hosted by the U.S. EPA in 2006 (Foos et al., 2008).

Consideration of life-stage-particular physiological characteristics in the dosimetry analysis

may result in a refinement to the human equivalent concentration (H_c) to insure relevance in risk assessment across life stages, or might conceivably conclude with multiple H_cS, and corresponding inhalation unit risk values (e.g., separate for childhood and adulthood). The RfC methodology, which is described in *Methods for Derivation of Inhalation Reference Concentrations and Applications of Inhalation Dosimetry* (U.S. EPA, 1994b), allows the user to incorporate population-specific assumptions into the models. The reader is referred to U.S. EPA guidance (U.S. EPA, 1994b) on how to make these adjustments.

There are no specific exposure factor assumptions in the derivation of Reference Doses (RfDs). The assessment of the potential for adverse health effects in infants and children is part of the overall hazard and dose-response assessment for a chemical. Available data pertinent to children's health risks are evaluated along with data on adults and the no-observed-adverse-effect-level (NOAEL) or benchmark dose (BMD) for the most sensitive critical effect(s), based on consideration of all health effects. By doing this, protection of the health of children will be considered along with that of other sensitive populations. In some cases, it is appropriate to evaluate the potential hazard to children separately from the assessment for the general population or other population subgroups.

Use of Exposure Factors Data in Probabilistic Analyses

Although the Handbook is not intended to provide complete guidance on the use of Monte Carlo and other probabilistic analyses, some of the data in the Handbook may be appropriate for use in probabilistic assessments. The use of Monte Carlo or other probabilistic analysis requires characterization of the variability of exposure factors and requires the selection of distributions or histograms for the input parameters of the dose equations presented earlier. The following suggestions are provided for consideration when using such techniques:

- The exposure assessor should only consider using probabilistic analysis when there are credible distribution data (or ranges) for the factor under consideration. Even if these distributions are known, it may not be necessary to apply this technique. For example, if only average exposure values are needed, these can often be computed accurately by using average values for each of the input parameters unless a nonlinear model is used. Probabilistic analysis is also not necessary when conducting assessments for screening purposes, i.e., to determine if unimportant pathways can be eliminated. In this case, bounding estimates can be calculated using maximum or near maximum values for each of the input parameters. Alternatively, the assessor may use the maximum values for those parameters that have the greatest variance.

- It is important to note that the selection of distributions can be highly site specific and dependent on the purpose of the assessment. In some cases, the selection of distributions is driven by specific legislation. It will always involve some degree of judgment. Distributions derived from national data may not represent local conditions. The assessor needs to evaluate the site-specific data, when available, to assess their quality and applicability. The assessor may decide to use distributional data drawn from the national or other surrogate population. In this case, it is important that the assessor address the extent to which local conditions may differ from the surrogate data.

- It is also important to consider the independence/dependence of variables and data used in a simulation. For example, it may be reasonable to assume that ingestion rate and contaminant concentration in foods are independent variables, but ingestion rate and body weight may or may not be independent.

In addition to a qualitative statement of uncertainty, the representativeness assumption should be appropriately addressed as part of a sensitivity analysis.

- Distribution functions to be used in probabilistic analysis may be derived by fitting an appropriate function to empirical data. In doing this, it should be recognized that in the lower and upper tails of the distribution the

data are scarce, so that several functions, with radically different shapes in the extreme tails, may be consistent with the data. To avoid introducing errors into the analysis by the arbitrary choice of an inappropriate function, several techniques can be used. One technique is using the empirical data itself rather than an analytic function. Another is to do separate analyses with several functions that have adequate fit but form upper and lower bounds to the empirical data. A third way is to use truncated analytical distributions. Judgment must be used in choosing the appropriate goodness-of-fit test. Information on the theoretical basis for fitting distributions can be found in a standard statistics text. Off-the-shelf computer software can be used to statistically determine the distributions that fit the data. Other software tools are available to identify outliers and for conducting Monte Carlo simulations.

- If only a range of values is known for an exposure factor, the exposure assessor has several options:

  - keep that variable constant at its central value;

  - assume several values within the range of values for the exposure factor.; calculate a point estimate(s) instead of using probabilistic analysis; or

  - assume a distribution. (The rationale for the selection of a distribution should be discussed at length.)

    There are, however, cases where assuming a distribution is not recommended. These include the following:

    -- data are missing or very limited for a key parameter;

    -- data were collected over a short time period and may not represent long-term trends (the respondent's usual behavior) - examples include food consumption surveys; activity pattern data;

    -- data are not representative of the population of interest because sample size was small or the population studied was selected from a local area and was therefore not representative of the area of interest; for example, soil ingestion by children; and

    -- ranges for a key variable are uncertain due to experimental error or other limitations in the study design or methodology; for example, soil ingestion by children.

CUMULATIVE EXPOSURES

The U.S. EPA recognizes that children may be exposed to mixtures of chemicals both indoors and outdoors through more than one pathway. New directions in risk assessments in the U.S. EPA put more emphasis on total exposures of multiple chemicals through multiple pathways (U.S. EPA, 1986a; 2000c). Over the last several years, the U.S. EPA has developed a methodology for assessing risk from multiple chemicals. For more information, the reader is referred to the U.S. EPA's *Framework for Cumulative Risk Assessment* (U.S. EPA, 2003b).

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Table 1. Summary of Recommended Exposure Factors for Children											
Age Group	0 to <1 mo	1 to <3 mos	3 to <6 mos	6 to <12 mos	1 to <2 yrs	2 to <3 yrs	3 to <6 yrs	6 to <11 yrs	11 to <16 yrs	16 to <18 yrs	18 to <21 yrs
Ingestion of Drinking Water (mL/day)— see Chapter 3											
Mean per capita	184	227	362	360	271	317	380	447	606	731	826
95th percentile per capita	839	896	1,056	1,055	837	877	1,078	1,235	1,727	1,983	2,540
Mean consumer only	470	552	556	467	308	356	417	480	652	792	895
95th percentile consumer only	858	1,053	1,171	1,147	893	912	1,099	1,251	1,744	2,002	2,565
Ingestion of Drinking Water (mL/kg-day) — see Chapter 3											
Mean per capita	52	48	52	41	23	23	22	16	12	11	12
95th percentile per capita	232	205	159	126	71	60	61	43	34	31	35
Mean consumer only	137	119	80	53	27	26	24	17	13	12	13
95th percentile consumer only	238	285	173	129	75	62	65	45	34	32	35
Ingestion of Water while Swimming (mL/hour) — see Chapter 3											
Mean	-							50		-	20
Upper percentile	-							100		-	70
Hand-to-Mouth Frequency (contacts/hour) — see Chapter 4											
Indoor Mean	-		28	19	20	13	15	7		-	
Indoor 95th percentile	-		65	52	63	37	54	21		-	
Outdoor Mean	-		-	15	14	5	9	3		-	
Outdoor 95th percentile	-		-	47	42	20	36	12		-	
Object-to-Mouth Frequency (contacts/hour) — see Chapter 4											
Mean	-			20		10		1		-	
95th percentile	-			-		-		-		-	
Object-to-Mouth Duration (minutes/hour) — see Chapter 4											
Mean	-		11		8	13			-		
95th percentile	-		26		22	16			-		

Table 1. Summary of Recommended Exposure Factors for Children (Continued)											
Age Group	0 to <1 mo	1 to <3 mos	3 to <6 mos	6 to <12 mos	1 to <2 yrs	2 to <3 yrs	3 to <6 yrs	6 to <11 yrs	11 to <16 yrs	16 to <18 yrs	18 to <21 yrs
Soil/Dust Ingestion (mg/day) — see Chapter 5											
Soil Central		-		30	50						
Dust Central		-		30	60						
Soil + Dust Central		-		60	100						
Soil pica Upper percentile		-		-	1,000						
Geophagy Upper percentile		-		-	50,000						
Inhalation Rate - Long-term (m^3/day) — see Chapter 6											
Mean	3.6	-	4.1	5.4	8.0	9.5	10.9	12.4	15.1	16.5	
95th percentile	7.1	-	6.1	8.1	12.8	15.9	16.2	18.7	23.5	27.6	
Inhalation Rate - Short-term (m^3/minute) — see Chapter 6											
Sleep/nap Mean		3.0E-03			4.5E-03	4.6E-03	4.3E-03	4.5E-03	5.0E-03	4.9E-03	
95th percentile		4.6E-03			6.4E-03	6.4E-03	5.8E-03	6.3E-03	7.4E-03	7.1E-03	
Sedentary Mean		3.1E-03			4.7E-03	4.8E-03	4.5E-03	4.8E-03	5.4E-03	5.3E-03	
95th percentile		4.7E-03			6.5E-03	6.5E-03	5.8E-03	6.4E-03	7.5E-03	7.2E-03	
Light Mean		7.6E-03			1.2E-02	1.2E-02	1.1E-02	1.1E-02	1.3E-02	1.2E-02	
95th percentile		1.1E-02			1.6E-02	1.6E-02	1.4E-02	1.5E-02	1.7E-02	1.6E-02	
Moderate Mean		1.4E-02			2.1E-02	2.1E-02	2.1E-02	2.2E-02	2.5E-02	2.6E-02	
95th percentile		2.3E-02			2.9E-02	2.9E-02	2.7E-02	2.9E-02	3.4E-02	3.7E-02	
Heavy Mean		2.6E-02			3.8E-02	3.9E-02	3.7E-02	4.2E-02	4.9E-02	4.9E-02	
95th percentile		4.1E-02			5.2E-02	5.3E-02	4.8E-02	5.9E-02	7.0E-02	7.3E-02	
Skin Surface Area - Total (m^2) — see Chapter 7											
Total Body Mean	0.29	0.33	0.38	0.45	0.53	0.61	0.76	1.08	1.59	1.84	
95th	0.34	0.38	0.44	0.51	0.61	0.70	0.95	1.48	2.06	2.33	

Table 1. Summary of Recommended Exposure Factors for Children (Continued)

Age Group		0 to <1 mo	1 to <3 mos	3 to <6 mos	6 to <12 mos	1 to <2 yrs	2 to <3 yrs	3 to <6 yrs	6 to <11 yrs	11 to <16 yrs	16 to <18 yrs	18 to <21 yrs
Skin Surface Area - Body Parts (m^2) — see Chapter 7												
Head	Mean	0.053	0.060	0.069	0.082	0.087	0.087	0.104	0.136	0.149	0.144	
	95th percentile	0.062	0.069	0.080	0.093	0.101	0.099	0.130	0.186	0.194	0.182	
Trunk	Mean	0.104	0.118	0.136	0.161	0.188	0.235	0.241	0.375	0.536	0.592	
	95th percentile	0.121	0.136	0.157	0.182	0.217	0.270	0.301	0.514	0.694	0.750	
Arms	Mean	0.040	0.045	0.052	0.062	0.069	0.072	0.108	0.137	0.205	0.282	
	95th percentile	0.047	0.052	0.060	0.070	0.079	0.083	0.135	0.188	0.266	0.356	
Hands	Mean	0.015	0.017	0.020	0.024	0.030	0.032	0.045	0.054	0.084	0.099	
	95th percentile	0.018	0.020	0.023	0.027	0.035	0.037	0.056	0.074	0.109	0.126	
Legs	Mean	0.060	0.068	0.078	0.093	0.122	0.142	0.207	0.301	0.498	0.592	
	95th percentile	0.070	0.078	0.091	0.105	0.141	0.162	0.259	0.413	0.645	0.750	
Feet	Mean	0.019	0.021	0.025	0.029	0.033	0.043	0.055	0.078	0.119	0.131	
	95th percentile	0.022	0.025	0.029	0.033	0.038	0.050	0.069	0.107	0.155	0.165	
Adherence of Solids to Skin (means; mg/cm^2) — see Chapter 7 for specific activities and age groups represented by these values												
Residential indoor		0.0041 (arms); 0.011 (hands); 0.0035 (legs); 0.010 (feet)										
Daycare (in & outdoors)		0.024 (arms); 0.099 (hands); 0.020 (legs); 0.071 (feet)										
Outdoor sports		0.012 (face); 0.011 (arms); 0.11 (hands); 0.031 (legs)										
Indoor sports		0.0019 (arms); 0.0063 (hands); 0.0020 (legs); 0.0022 (feet)										
Activities with soil		0.054 (face); 0.046 (arms); 0.17 (hands); 0.051 (legs); 0.20 (feet)										
Playing in mud		11 (arms); 47 (hands); 23 (legs); 15 (feet)										
Playing in sediment		0.040 (face); 0.17 (arms); 0.49 (hands); 0.70 (legs); 21 (feet)										
Body Weight (kg) — see Chapter 8												
Mean		4.8	5.9	7.4	9.2	11.4	13.8	18.6	31.8	56.8	71.6	
Total Fruit Intake (g/kg-day)[a] — see Chapter 9												
Mean per capita		5.7				6.2		4.6	2.4	0.8		
95th percentile per capita		21				19		14	8.8	3.5		
Mean consumer only		10				6.9		5.1	2.7	1.1		
95th percentile consumer		26				19		15	9.3	3.8		

Table 1. Summary of Recommended Exposure Factors for Children (Continued)											
Age Group	0 to <1 mo	1 to <3 mos	3 to <6 mos	6 to <12 mos	1 to <2 yrs	2 to <3 yrs	3 to <6 yrs	6 to <11 yrs	11 to <16 yrs	16 to <18 yrs	18 to <21 yrs
Total Vegetable Intake (g/kg-day)[a] — see Chapter 9											
Mean per capita	4.5				6.9		5.9	4.1	2.9		
95th percentile per capita	15				17		15	9.9	6.9		
Mean consumer only	6.2				6.9		5.9	4.1	2.9		
95th percentile consumer	16				17		15	9.9	6.9		
Fish and Shellfish Intake (g/kg-day)[a] — see Chapter 10											
General Population											
Total Fish											
Mean per capita	-						0.43	0.28	0.23	0.16	-
95th percentile per capita	-						3.0	1.9	1.5	1.3	-
Mean consumer only	-						4.2	3.2	2.2	2.1	-
95th consumer	-						10	8.7	6.2	6.6	-
Marine											
Mean per capita	-						0.31	0.20	0.15	0.10	-
95th percentile per capita	-						2.3	1.5	1.3	0.46	-
Mean consumer only	-						3.7	2.8	2.0	2.0	-
95th percentile consumer	-						9.3	8.0	5.2	6.5	-
Freshwater											
Mean per capita	-						0.12	0.08	0.08	0.07	-
95th percentile per capita	-						0.71	0.35	0.48	0.29	-
Mean consumer only	-						2.3	1.8	1.3	1.4	-
95th percentile consumer	-						7.2	6.2	4.4	3.3	-
Recreational Marine - No age-specific recommendations; see Chapter 10											
Recreational Freshwater - No age-specific recommendations; see Chapter 10											
Native American - No age-specific recommendations; see Chapter 10											

Table 1. Summary of Recommended Exposure Factors for Children (Continued)											
Age Group	0 to <1 mo	1 to <3 mos	3 to <6 mos	6 to <12 mos	1 to <2 yrs	2 to <3 yrs	3 to <6 yrs	6 to <11 yrs	11 to <16 yrs	16 to <18 yrs	18 to <21 yrs
Total Meat Intake (g/kg-day)[a] — see Chapter 11											
Mean per capita	1.2				4.1		4.1	2.9	2.1		
95th percentile per capita	6.7				9.8		9.4	6.5	4.8		
Mean consumer only	3.0				4.2		4.2	2.9	2.1		
95th percentile consumer	9.2				9.8		9.4	6.5	4.8		
Total Dairy Intake (g/kg-day)[a] — see Chapter 11											
Mean per capita	13				37		23	14	5.6		
95th percentile per capita	49				88		49	32	16		
Mean consumer only	16				37		23	14	5.6		
95th percentile consumer	58				88		49	32	16		
Total Fat Intake (g/kg-day)[a] — see Chapter 11											
Mean per capita	5.2	4.5	4.1	3.7	4.0	3.6	3.4	2.6	1.6	1.3	
95th percentile per capita	16	11	8.2	7.0	7.1	6.4	5.8	4.2	3.0	2.7	
Mean consumer only	7.8	6.0	4.4	3.7	4.0	3.6	3.4	2.6	1.6	1.3	
95th percentile consumer	16	12	8.3	7.0	7.1	6.4	5.8	4.2	3.0	2.7	
Total Grain Intake (g/kg-day)[a] — see Chapter 12											
Mean per capita	2.5				6.4		6.3	4.3	2.5		
95th percentile per capita	8.6				12		12	8.2	5.1		
Mean consumer only	3.6				6.4		6.3	4.3	2.5		
95th percentile consumer	9.2				12		12	8.2	5.1		

Table 1. Summary of Recommended Exposure Factors for Children (Continued)											
Age Group	0 to <1 mo	1 to <3 mos	3 to <6 mos	6 to <12 mos	1 to <2 yrs	2 to <3 yrs	3 to <6 yrs	6 to <11 yrs	11 to <16 yrs	16 to <18 yrs	18 to <21 yrs
Home-produced Food Intake (g/kg-day)[b] — see Chapter 13											
Fruits Mean	-				8.7		4.1	3.6	1.9		
95th percentile	-				60.6		8.9	15.8	8.3		
Vegetables Mean	-				5.2		2.5	2.0	1.5		
95th percentile	-				19.6		7.7	6.2	6.0		
Meats Mean	-				3.7		3.6	3.7	1.7		
95th percentile	-				10.0		9.1	14.0	4.3		
Fish Mean	-							2.8	1.5		
95th percentile	-							7.1	4.7		
Total Food Intake (g/kg-day) — see Chapter 14											
Mean per capita	20	16	28	56	90	74	61	40	24	18	
95th percentile per capita	61	40	65	134	161	126	102	70	45	35	
Human Milk Intake (mL/day) — see Chapter 15											
Mean	510	690	770	620	NA						
Upper percentile	950	980	1,000	1,000	NA						
Human Milk Intake (mL/kg-day) — see Chapter 15											
Mean	150	140	110	83	NA						
Upper percentile	220	190	150	130	NA						
Lipid Intake from Human Milk (mL/day) — see Chapter 15											
Mean	20	27	30	25	NA						
Upper percentile	38	40	42	42	NA						

Table 1. Summary of Recommended Exposure Factors for Children (Continued)												
Age Group		0 to <1 mo	1 to <3 mos	3 to <6 mos	6 to <12 mos	1 to <2 yrs	2 to <3 yrs	3 to <6 yrs	6 to <11 yrs	11 to <16 yrs	16 to <18 yrs	18 to <21 yrs
Lipid Intake from Human Milk (mL/kg-day) — see Chapter 15												
Mean		6.0	5.5	4.2	3.3	NA						
Upper percentile		8.7	8.0	6.0	5.2	NA						
Activity Factors — see Chapter 16												
Mean (minutes/day)												
Indoors, total	Mean	1,440	1,432	1,414	1,301	1,353	1,316	1,278	1,244	1,260	1,248	
Outdoors, total	Mean	0	8	26	139	36	76	107	132	100	102	
Indoors, at residence	Mean	1,108				1,065	979	957	893	889	833	
	95th	1,440				1,440	1,296	1,355	1,275	1,315	1,288	
Showering	Mean	15				20	22	17	18	18	20	
	95th	-				-	44	34	41	40	45	
Bathing	Mean	19				23	23	24	24	25	33	
	95th	30				32	45	60	46	43	60	
Playing on sand/gravel	Mean	18				43	53	60	67	67	83	
	95th	-				121	121	121	121	121	-	
Playing on grass	Mean	52				68	62	79	73	75	60	
	95th	-				121	121	121	121	121	-	
Playing on dirt	Mean	33				56	47	63	63	49	30	
	95th	-				121	121	121	121	120	-	
Mean (minutes/month)												
Swimming	Mean	96				105	116	137	151	139	145	
	95th	-				-	181	181	181	181	181	

Table 1. Summary of Recommended Exposure Factors for Children (Continued)											
Age Group	0 to <1 mo	1 to <3 mos	3 to <6 mos	6 to <12 mos	1 to <2 yrs	2 to <3 yrs	3 to <6 yrs	6 to <11 yrs	11 to <16 yrs	16 to <18 yrs	18 to <21 yrs
Consumer Products — see Chapter 17											
No age-specific recommendations; see Chapter 17.											

[a] Analysis was conducted using slightly different age groups than those recommended in *Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants* (U.S. EPA, 2005a). Data were placed in the recommended age categories closest to those used in the analysis.

[b] Analysis was conducted prior to Agency's issuance of *Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants* (U.S. EPA, 2005a). Thus, age groups in the original study are slightly different than those presented here. See chapters of the *Child-Specific Exposure Factors Handbook* (U.S. EPA, 2008a) for details.

\- = No data available and/or no recommendation made.

NA = Not applicable.

Table 2. Characterization of Variability in Exposure Factors

Exposure Factors	Average	Median	Upper percentile	Multiple Percentiles
Ingestion of water and other select liquids	√	√	√	√
Non-dietary ingestion	√	√	√	
Soil and dust ingestion	√	√	√[a]	
Inhalation rate	√	√	√	√
Surface area	√	√	√	√
Soil adherence	√			
Body weight	√	√	√	√
Intake of fruits and vegetables	√	√	√	√
Intake of fish and shellfish	√	√	√	√
Intake of meats, dairy products, and fats	√	√	√	√
Intake of grain products	√	√	√	√
Intake of home produced foods	√	√	√	√
Total food intake	√	√	√	√
Human milk intake	√		√	
Time indoors	√			
Time outdoors	√			
Time showering	√	√	√	√
Time bathing	√	√	√	√
Time swimming	√	√	√	√
Time playing on sand/gravel	√	√	√	√
Time playing on grass	√	√	√	√
Time playing on dirt	√	√	√	√

[a] Soil pica and geophagy.

√ = Data available.

Table 3. Considerations Used to Rate Confidence in Recommended Values

General Assessment Factors	Increasing Confidence	Decreasing Confidence
Soundness		
Adequacy of Approach	The studies used the best available methodology and capture the measurement of interest.	There are serious limitations with the approach used; study design does not accurately capture the measurement of interest.
	As the sample size relative to that of the target population increases, there is greater assurance that the results are reflective of the target population.	Sample size is too small to represent the population of interest.
	The response rate is greater than 80% for in-person interviews and telephone surveys, or greater than 70 % for mail surveys.	The response rate is less than 40 %.
	The studies analyzed primary data.	The studies are based on secondary sources.
Minimal (or defined) Bias	The study design minimizes measurement errors.	Uncertainties with the data exist due to measurement error.
Applicability and Utility		
Exposure Factor of Interest	The studies focused on the exposure factor of interest.	The purpose of the studies was to characterize a related factor.
Representativeness	The studies focused on the U.S. population.	Studies are not representative of the U.S. population.
Currency	The studies represent current exposure conditions.	Studies may not be representative of current exposure conditions.
Data Collection Period	The data collection period is sufficient to estimate long-term behaviors.	Shorter data collection periods may not represent long-term exposures.
Clarity and Completeness		
Accessibility	The study data could be accessed.	Access to the primary data set was limited.
Reproducibility	The results can be reproduced, or methodology can be followed and evaluated.	The results cannot be reproduced, the methodology is hard to follow, and the author(s) cannot be located.
Quality Assurance	The studies applied and documented quality assurance/quality control measures.	Information on quality assurance/control was limited or absent.
Variability and Uncertainty		
Variability in Population	The studies characterize variability in the population studied.	The characterization of variability is limited.
Uncertainty	The uncertainties are minimal and can be identified. Potential biases in the studies are stated or can be determined from the study design.	Estimates are highly uncertain and cannot be characterized. The study design introduces biases in the results.
Evaluation and Review		
Peer Review	The studies received high level of peer review (e.g., they are published in peer-reviewed journals).	The studies received limited peer review.
Number and Agreement of Studies	The number of studies is greater than three. The results of studies from different researchers are in agreement.	The number of studies is one. The results of studies from different researchers are in disagreement.

Table 4. Summary of Confidence Ratings For Exposure Factor Recommendations	
Exposure Factor	Overall Confidence Rating
Ingestion of drinking water— see Chapter 3	Medium to High
Ingestion of water while swimming — see Chapter 3	Low
Mouthing frequency and duration — see Chapter 4	Low
Soil and dust ingestion — see Chapter 5	Low
Inhalation rates— see Chapter 6	Medium
Skin surface area — see Chapter 7	Medium for Total Surface Area Low for Surface Area of Individual Body Parts
Soil adherence — see Chapter 7	Low
Body Weight — see Chapter 8	High
Intake of Fruits and Vegetables — see Chapter 9	High for means Low for long-term upper percentiles
Intake of Fish and Shellfish — see Chapter 10	High for mean Medium for upper percentile
Intake of Meats, Dairy, and Fats — see Chapter 11	High for means Low for long-term upper percentiles
Intake of Grains — see Chapter 12	High for means Low for long-term upper percentiles
Intake of Home-produced Foods — see Chapter 13	Low to Medium for means and short-term distributions Low for long-term distributions
Total Food Intake — see Chapter 14	Medium
Human Milk Intake — see Chapter 15	Medium
Activity Factors — see Chapter 16	Medium for means Low for upper percentiles

Table 5. Age-Dependent Potency Adjustment Factor (ADAF) by Exposure Age Group [a]

Exposure Age Group[a]	Exposure Duration (years)	ADAF (Age-Dependent Potency Adjustment Factor)
Birth to < 1 mo	0.083	10×
1 to <3 mos	0.167	10×
3 to <6 mos	0.25	10×
6 to <12 mos	0.5	10×
1 to <2 yrs	1	10×
2 to <3 yrs	1	3×
3 to <6 yrs	3	3×
6 to <11 yrs	5	3×
11 to <16 yrs	5	3×
16 to <21 yrs	5	1×
>21 yrs (21 to <70 yr)	49	1×

[a] Integrating U.S. EPA's *Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants* (U.S. EPA, 2005a) with U.S. EPA's *Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens* (U.S. EPA, 2005c) for those contaminants which act via a mutagenic mode of action.

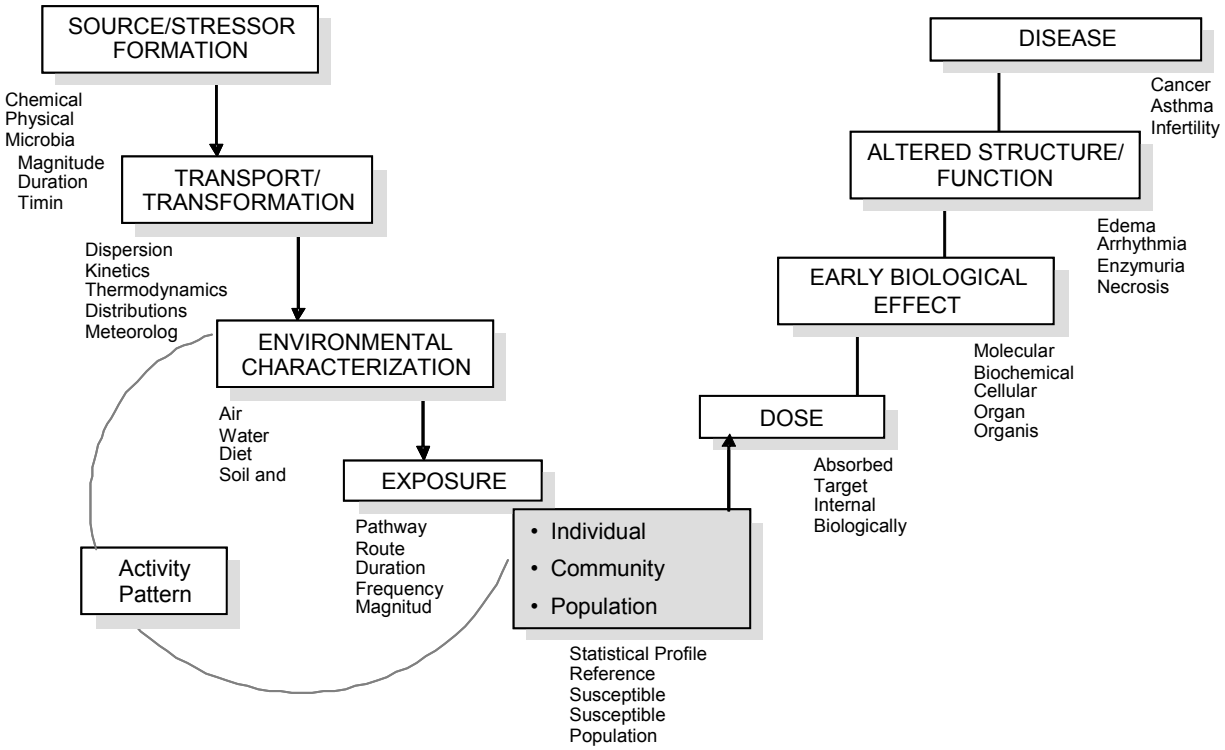

Figure 1. The Exposure-Dose-Effect Continuum

The exposure-dose-effect continuum depicts the trajectory of a chemical or agent from its source to an effect. The chemical or agent can be transformed and transported through the environment via air, water, soil, dust, and diet. Children can become in contact with the chemical through inhalation, ingestion, or skin/eye contact. The child's physiology, behavior, and activity patterns as well as the concentration of the chemical will determine the magnitude, frequency, and duration of the exposure. The exposure becomes an absorbed dose once the chemical crosses the absorption barrier (i.e., skin, lungs, eyes, gastrointestinal tract, placenta). Interactions of the chemical or its metabolites with a target tissue may lead to an adverse health outcome. The text under the boxes indicates the specific information that may be needed to characterize each box in the exposure-dose-effect continuum.

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