Original Article

Changes in Children's Exposure as a Function of Age and the Relevance of Age Definitions for Exposure and Health Risk Assessment

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Abstract and Introduction

Abstract

Objective: The objective of this study was to review and synthesize the existing exposure information available to support the characterization and estimation of children's environmental health risks as a function of age.
Method: This includes a review of the existing peer-reviewed literature and reports from the US Environmental Protection Agency (EPA) up through January 1, 2003 for information about exposure data for American children with a focus on identifying the age categories used and data gaps that limit our ability to estimate children's risks from exposure to environmental hazards.
Results: On the basis of this synthesis, several key data gaps emerge that suggest some areas in which exposure assessors may want to focus attention, including current breast milk consumption by infants and breastfeeding information for children over age 1 year; children's food-handling practices and how these lead to exposure (eg, by eating with dirty hands or by eating food that has dropped onto a contaminated surface); fish-intake rates for young children and for children whose families include sport fishers or whose families rely on self-caught fish for sustenance; incidental and intentional soil intake by children; soil adherence for dermal exposure; relationships between various microactivities, macroactivities, and microenvironments where children spend time; and a correlation between exposure factors and growth (ie, how children's exposure behaviors change over time). In contrast, relatively good exposure information exists for characterizing children's growth and water ingestion, and at least some exposure information exists for the wide ranges of exposures of regulatory interest.
Conclusion: Given the currently available data, exposure assessors can estimate children's potential health risks from a number of different types of exposure, but longitudinal data are needed to reduce the significant uncertainties that arise from reliance on currently available data, and a number of dose-response challenges remain.

Introduction

During the past decade, improving the lives of children has emerged as a priority on the National Agenda.[1] In the public and environmental health areas, this priority emerged prominently in President Clinton's Executive Order 13045, which required federal agencies to ensure that their "policies, programs, activities, and standards address disproportionate risks to children that result from environmental health risks or safety risks." Congress also established children's health as a priority in changes to statutory requirements in the 1996 Food Quality Protection Act (FQPA) and the Safe Drinking Water Act. For example, FQPA created a demand for estimating aggregate exposure (ie, the amount of exposure from multiple pathways for the same substance) and cumulative risk (ie, the risk from all substances that act with the same mechanism of toxicity over all of the multiple pathways in which they may act).

The focus on children's health raises many challenges for exposure and risk analysts. Childhood represents distinct phases of human life, and children possess unique characteristics that distinguish them from adults. From birth to adulthood, their physiology and behavior constantly change, making them a "moving target" for exposure and risk assessment. This leads to a number of key questions:

- How should the age-related changes in children's behavior and physiology be considered when assessing children's exposure to environmental contaminants?

- What is the most appropriate way to categorize the available data into age groups when assessing children's exposure?
- Given the rapid change in modern society, how representative are data from previous studies for today's children?
- What is the most appropriate way to estimate childhood exposure given the limitations in currently available exposure information?
- What further research is needed to provide the data necessary for estimating children's exposure and what short-term and longer-term data could provide the missing information?

With current discussions about the possibility of a National Children's Study, a proposed multimillion dollar longitudinal study that may provide information about approximately 100,000 American children potentially followed for 21 years,[2] risk analysts must ask important questions about what data would be the most valuable for researchers to obtain given the inevitability of difficult choices related to sample collection and survey design in the context of limited resources (eg, financial, technological, and research subject willingness to participate if the study presents too large a burden). This article synthesizes the most current and relevant information available regarding children's anatomic and behavioral changes and how these affect assessments of exposure. This article provides the important context for discussions about the value of obtaining additional exposure-factor information for children.

1. Introduction

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2. Methods

This effort began with a literature review process that involved searching the Medline and ISI Web of Science electronic indexes for articles that collected environmental exposure-factor data for children. Search terms included the words "child" or "children" and "exposure" as well as each exposure-factor term and variants (eg, "soil ingestion" and "soil intake"). In addition, searching included using the ISI Web of Science for studies that cited the papers that contained information about children's exposure and a review of the cited references in papers of prior studies that contained relevant data. The process also included a review of the *Child-Specific Exposure Factors Handbook*,[3] compiled by the US Environmental Protection Agency (EPA), and a review of all abstracts published relating to children in *Risk Analysis: An International Journal*, *Human and Ecological Risk Assessment*, *Journal of Exposure Analysis and Environmental Epidemiology*, and *Environmental Health Perspectives*. This literature search included papers published by January 1, 2004.

Given the large scope of the topic, this article is divided into sections. Section 3 reviews some of the key issues regarding children's exposure and risk assessment. Section 4 presents a series of equations developed by Cohen Hubal and colleagues[4] that provide a useful approach for estimating exposure in children, with a similar approach appearing recently.[5] These equations utilize a number of exposure factors, including child-based exposure factors concerning physiology and behavior, as well as environmental factors, such as the concentration of contaminant to which a child may be exposed. The *Child-Specific Exposure Factors Handbook*[3] provides some recommended values for exposure factors on the basis of existing data, but does not specify exposure factors as a function of consistent ages or age ranges. Sections 5 through 9 of this article synthesize and discuss the available data for each of the child-based exposure factors used in the equations described in Section 4. Section 5 discusses anatomic changes that occur during growth (ie, body weight and skin surface area [SA]). Sections 6, 7, 8, and 9 discuss the behavioral factors related to ingestion (food intake, drinking water consumption, breast milk, fish consumption, soil ingestion, and other nondietary exposure factors); inhalation; dermal exposure; and time-activity patterns, respectively. Finally, Section 10 characterizes the challenges and constraints that analysts face when using these data in exposure and health risk assessments.

3. Key Issues for Children's Exposure

Children experience remarkable change from birth to adulthood. Two of the most dramatic changes are rapid increases in weight and height, as summarized by the growth charts available in popular pediatric textbooks (eg, see the reference list[6]), which result in dramatic changes in body proportions that occur from birth to adulthood. In addition to physical growth, children pass through numerous other physiologic, psychologic, social, and behavioral phases. These phases have different durations, with popular pediatric textbooks (eg, see the reference list[6]) also providing a typical chart for normal developmental milestones. In many of these charts, the milestones for fine motor, gross motor, language, and personal or social development are categorized separately. These charts typically do not include anatomic changes, such as teething, that could have an impact on children's exposure and risk. Some phases, such as crawling and mouthing objects, are common to all (or almost all) developing children. Other phases are common only to children with specific characteristics (eg, kids with fair skin), whereas others may depend on child-specific activity patterns (eg, children who swim, children who consume a lot of a particular food, or teenage girls who wear makeup).

Different developmental stages, milestones, and activities may have different significance for physicians and exposure or risk assessors. For example, developmental milestones, such as talking and reading, may be important to physicians but generally not to exposure and risk assessors focusing on estimating the risk from a substance in the environment. Conversely, detailed information about everyday behaviors, such as the amount of water consumed or time spent playing outside, may be significant to exposure and risk assessors but not to physicians.

Many aspects of child development reflect continuous change, although they may not be recorded as such. For example, physical growth is continuous even though measurements are typically collected only at discrete points in time (eg, at annual physical exams) and the growth rate is not constant (eg, growth spurts). The developmental phases or time periods that are relevant to a risk assessment depend on the type of assessment. For lifetime cancer risks, childhood exposure is simply 1 component of the entire lifetime. In contrast, when assessing acute hazards, exposure and risk assessors may be most interested in the peak exposure for a young child over the course of an hour or less. For some noncancer health effects, the relevant exposure duration could be a day, a week, a year, or some other period of time. For toxic effects that only occur if the child is exposed during a certain period of development (eg, during the formation of the limbs *in utero*), only exposure during that developmental window may be significant (see the literature for a review of critical windows of exposure for children[7]).

Although children have higher daily requirements for food, water, and oxygen per unit of body weight and a higher ratio of SA to volume than adults and children may process substances with different pharmacokinetics and pharmacodynamics leading to a different metabolism, absorption, and excretion of substances from adults, this does not necessarily mean that they are more vulnerable to health effects than adults.[8-13] In fact, their exposures and risks can be higher or lower than those experienced by adults, and the risks must be assessed on a case-by-case basis.[8]

Variability is a key challenge for children's exposure assessment, with children of the same age often exhibiting tremendous differences in their exposure. Combined with the rapid growth that occurs during childhood, the variability in the population of children generally limits the extent to which fixed age ranges can be used for assessing children's development, exposure, and risk. Nonetheless, defining some standard age ranges for children would be helpful, particularly in dealing with data gaps and mismatches that arise in the estimation of aggregate exposure and cumulative risk. Ideally, analysts would know everything they need to know for every child and would have good estimates of the exposures that children really experience. Because perfect data are not available, exposure and risk assessors typically use multiple data sources when assessing aggregate exposure and cumulative risk. However, these data often have a wide array of age categories, which makes direct modeling of the aggregate exposures for children very difficult, leaving analysts to model "hypothetical" children by piecing together data while exercising caution to avoid combinations that could not really exist (eg, children who live 25 hours/day or consume more food than biologically possible). The ability to model children's exposure should improve over time with the collection of better information, but this depends on ensuring that research focuses on filling the existing gaps.

Another challenge when assessing children's exposure is the extent to which the available exposure data represent the population of interest.[14]. Exposure data are collected for a specific group of people, in a specific place, and at a specific time. They can be used in a risk assessment only to the extent that they are sufficiently relevant to the population being assessed in the current time and place. The rapid pace of social and behavioral change may diminish the relevance of study data. For example:

- With increased globalization in the past decade, many fruits and vegetables that once were available only seasonally or in some places now are available virtually year round;
- Many people consume an ever-increasing percentage of food away from home; and
- Diets for children, which have historically included a large amount of fresh produce and tap water, are shifting to include larger amounts of processed food and bottled water.

The deaths of children caused by air bags demonstrate the implications of failing to adequately characterize children's risks as potentially very different from those of adults,[15] and the fact that children are undergoing development means that analysts must develop approaches to characterize the impacts of health effects at different times on the developmental trajectories of children.[16]

4. Exposure Equations

Cohen Hubal and coworkers[4] reviewed many of the typical factors that influence children's exposure and discussed the data available to characterize these factors. They defined 3 terms, which they used to develop a series of equations for estimating exposure:

- A microenvironment (me) is the location a child occupies for a specified period of time. Examples include outdoors-home lawn and indoors-home kitchen.
- A macroactivity (ma) is a highly aggregated description of what a child is doing during a specified period of time. Examples include playing games, watching television, eating, running, sleeping, and crawling.
- A microactivity (mi) is a detailed description of an event that takes place during a macroactivity. Examples include hand contact with a floor or an object and mouthing a hand or an object.

Cohen Hubal and coworkers[4] provided several equations for estimating exposure, which appear as Equations 1, 2, 3, 4, and 6 below. Although these were not discussed or developed by Cohen Hubal and colleagues,[4] Equations 5 and 7 have been added because they reflect typical exposure relationships used by exposure and risk analysts.[5]

Equation 1: Inhalation Exposure

Inhalation exposure averaged over a day for a single me/ma ($E_{ime/ma}$) (in mg/day) is defined as:

$$E_{ime/ma} = IR_{ma} \cdot T_{me/ma} \cdot C_{ame} \quad (1)$$

in which IR_{ma} is the child's respiration rate representing his or her activity level for that ma (m^3/hour), $T_{me/ma}$ is the time spent in that me/ma during the 24-hour period (hour/day), and C_{ame} is the air concentration measured in the me (mg/m^3).

Equation 2: Dermal Exposure (Series of Contacts With Contaminated Medium)

Dermal exposure can be estimated individually for each me and ma with empirically derived transfer coefficients to aggregate the mass transfer associated with a series of contacts with a contaminated medium.[4] Dermal exposure averaged over a day for a single me/ma ($E_{dme/ma}$) (in mg/day) is defined as:

$$E_{dme/ma} = DTC_{der} \cdot T_{me/ma} \cdot C_{surf} \quad (2)$$

in which DTC_{der} is the dermal transfer coefficient for the me/ma (cm^2/hour), $T_{me/ma}$ is the time spent in that me/ma during the 24-hour period (hour/day), and C_{surf} is the total contaminant loading on the surface (mg/cm^2).

Equation 3: Dermal Exposure (Single Contact With Contaminated Medium)

Dermal exposure can also be modeled as a series of discrete transfers resulting from each contact with a contaminated medium.[4] Dermal exposure averaged over a day for each mi ($E_{der/mi}$) (in mg/day) can be defined as:

$$E_{der/mi} = TE \cdot SA \cdot EF \cdot DSL \cdot C_{surf} \quad (3)$$

in which TE is the transfer-efficiency fraction transferred from surface to skin (unitless), SA is the area of surface that is contacted (cm^2/event), EF is the frequency of contact event over a 24-hour period (events/day), DSL is the dermal soil loading on the surface (mg/cm^2), and C_{surf} is the contaminant concentration in soil (mg contaminant/mg soil).

Equation 4: Dietary Ingestion Exposure (Food Consumption -- Complex)

Cohen Hubal and colleagues[4] defined dietary ingestion exposure averaged over a day (E_{diet}) (in mg/food item) as the amount of exposure that results directly from the food plus the amount that comes from the food contacting a contaminated surface *i* times and a child's contaminated hand *j* times:

$$E_{diet} = W_T \cdot C_{food} + \text{Sigma}_i \, [TE_{S/F} \cdot SA_{S/F} \cdot EF_{S/F} \cdot C_{surf}] + \text{Sigma}_j \, [TE_{H/F} \cdot SA_{H/F} \cdot EF_{H/F} \cdot C_{hand}] \quad (4)$$

in which W_T is the amount of the individual food consumed (g/food item), C_{food} is the contaminant concentration on the food item as prepared for consumption (mg/g), $TE_{S/F}$ is the transfer-efficiency fraction transferred from surface to food (which may be a function of the duration of contact, moisture, surface type, etc) (unitless), $SA_{S/F}$ is the area of the food item in contact with the contaminated surface (cm^2/event), $EF_{S/F}$ is the frequency of surface-to-food contact events that occurs during the consumption of the food item (events/food item), C_{surf} is the contaminant loading on the contacted surface (mg/cm^2), $TE_{H/F}$ is the transfer-efficiency fraction transferred from hand to food (unitless), $SA_{H/F}$ is the area of food item in contact with contaminated hand (cm^2/event), $EF_{H/F}$ is the frequency of hand-to-food contact events that occur during consumption of the food item (events/food item), and C_{hand} is the contaminant loading on a child's hand (mg/cm^2).

Converting this exposure to units of mg/day requires multiplying by the number of food items consumed per day (N) (in food items/day), and estimating the total exposure to a substance from food also requires summing the results for all appropriate specific foods.

Equation 5: Dietary Ingestion Exposure (Food Consumption -- Simple)

Equation 4 provides a relatively sophisticated assessment of exposure from food consumption. However, when some of the exposure factors required for Equation 4 are not known, dietary ingestion exposure can be estimated by the following simpler traditional equation in which dietary ingestion exposure averaged over a day (E_{ing}) (in mg/day) is defined as:

$$E_{ing} = IR_{food} \cdot C_{food} \quad (5)$$

in which IR_{food} is the amount of the specific food that the child consumes in a day (g/day) and C_{food} is the concentration of the contaminant in the food (mg/g).

Equation 6: Nondietary Ingestion

Nondietary ingestion exposure averaged over a day for each mi in which it occurs ($E_{nding/mi}$) (in mg/day) can be defined as:

$$E_{nding/mi} = TE_{xm} \cdot SA_{x} \cdot EF \cdot C_{x} \quad (6)$$

in which x is the object that is mouthed (including hand), TE_{xm} is the transfer-efficiency fraction transferred from object or hand to mouth (unitless), SA_{x} is the area of object or hand that is mouthed (cm^2/event), EF is the frequency of the mouthing event over a 24-hour period (events/day), and C_{x} is the total contaminant loading on hand or object (mg/cm^2).

Estimating Total Exposure

To estimate total exposure for an entire day or longer, exposures must be added and averaged appropriately. For air pollutants, total exposure has traditionally meant adding the exposures from the various mes that the child experiences over the course of a day. However, the appropriate dose-response relationship for the health effect of concern will determine the appropriate dose metric, which determines the level of aggregation and averaging required. For most risk analyses, estimating exposure typically requires averaging over a longer time period than a day (ie, a year or a lifetime). For this reason, it is very important for exposure and risk assessors to recognize that short-term exposures tend to be more variable than long-term ones. For example, the amount of daily exposure to a contaminant on grapes will be 0 on days when no grapes are consumed and not 0 on days when grapes are consumed. Over the longer term, the average grape consumption will be greater than 0, but less than the highest daily-consumption amount. Thus, over time there will be regression to the mean. This phenomenon must be properly accounted for in exposure and risk assessment, but remains challenging given the lack of sufficient longitudinal data.

Equation 7: Dose Estimation

To estimate dose (mg/kg/day) for risk assessments, the results of the above equations are divided by body weight (BW) of the exposed individual or some function of body weight:

$$Dose = E/BW \quad (7)$$

in which E is exposure (mg/d) and BW is body weight (kg).

Note that some exposure factors (eg, ingestion rate and skin surface area) can be expressed as a function of body weight, and when a correlation exists between exposure factors this correlation should be considered. Equation 7 is used only in situations in which BW is not already included in the exposure factor.

Discussion of Anatomic and Behavioral Exposure Factors

Sections 5 through 9 of this article discuss the various anatomic and behavioral exposure factors used in Equations 1 through 7. For each exposure factor, the sections describe the types of information needed in the context of exposure models, assess the extent to which the data are accessible and the age categories can be modified, and discuss the quantification of variability and uncertainty in the information. Also, for each exposure factor, a summary table is provided that lists the key available data sources. The tables also list the age categories used by each source, the number of subjects in each age group (when available), and a general assessment of the data confidence rating on the basis of the criteria and judgments given in the EPA's *Child-Specific Exposure Factors Handbook*.[3] The last column provides the author's qualitative assessment of the value of the existing information for exposure assessments in general (ie, the likely utility of the data in the context of risk-management decisions).

5. Anatomic Changes During Growth

5.1. BW

BW is critical to appropriately assess dose (see Equation 7). Data from large cohorts can be used to develop complete growth charts and to characterize the variability in BW around each age. Any age grouping is possible because these data are continuous and they may be converted into discrete age bins. Table 1 summarizes the age groupings provided by the existing data sources. In 1979, Hamill and coworkers[17] provided growth charts for American children from birth through 36 months, and the most recent and extensive studies of BWs for American children come from the National Center for Health Statistics (NCHS) National Health and Nutrition Examination Survey (NHANES) II and III.[18,19] NHANES II provided BW data for children between 6 months and 19 years that Burmaster and associates[20] reanalyzed and found to distribute following a lognormal distribution. The data from NHANES III[19] provide BW data for children and young adults between 2 months and 24 years of age, and the recent study by Hattis and colleagues[21] explored the variability in distributions of BWs for children as a function of sex and age, finding some important deviations from the expected lognormal fits. Since the NHANES III data are reported by sex for each month up to 36 months and for each year of age up to 20 years, analysts can rely on this rich data set to combine the results into different age ranges and quantify variability among children of the same age. The largest existing child anthropometric data set collected in the 1970s, under contract to the US Consumer Product Safety Commission, also contains BW measurements for 4027 infants and children representative of the US population at that time.[22] Current trends of increasing numbers of overweight and obese children represent an important consideration for characterizing children's risks. Similarly, recent advances in medical technology also allow many more low birth weight (less than 2500 g) and very low birth weight (less than 1500 g) infants to survive. This may lead to greater variance in the weights of infants and children as a function of age.

Remarkably, weight change of an individual child as a function of age and the correlation of BW with other exposure factors are less well studied. For example, do children born at the 90th weight percentile remain at the 90th percentile or even continue to be larger than the median child? Anecdotal evidence of small babies growing up to be large adults and large babies growing up to be small adults suggests that genetics and other factors play a role in changes of BW, and the limited evidence of body mass index changes as a function of age suggests that the pattern of body mass index from ages 2 to 25 years shows a stronger effect on subsequent adult overweight than birth weight or the adult lifestyle variables observed.[23] However, no large studies of longitudinal data exist concerning BW as a function of age over the duration of childhood. Although access to this type of longitudinal data may not be very significant when analyzing chronic effects for an average child (eg, the median or mean), if the analysis focuses on a low-percentile individual child (eg, a 5th-percentile child), then it may be important to factor in the tendency of regression to the mean and to be cautious in constructing a 5th-percentile time-weighted average estimate of BW with weights observed for 5th-percentile individuals at different ages.

5.2. Skin SA (SA and SA/BW)

Skin SA information is most often used in dermal assessments, which also incorporate a number of behavioral factors, as discussed in Section 9. Direct SA measurements are much less common than BW measurements. For example, physicians frequently measure BW and height (which correlate with skin SA), but they rarely measure body SA. Instead, skin SA is generally calculated from BW with relationships and data collected 65 years ago by Boyd.[24]Table 2 summarizes the age groupings for SA from the available studies that have analyzed 401 measurements for different age ranges.[25,26] Note that insufficient data exist for children under age 2 years and for very small infants (eg, low birth weight infants), and consequently analysts must extrapolate to estimate SA for these children because Boyd's relationship for estimating SA from height and weight data did not include them. Snyder and colleagues[22] provides dimensions about specific body parts that can also be used to estimate SA more directly.

Many of the ideas discussed in Section 5.1 for the BW factor apply to SA as well. Estimates for SA could be updated to reflect the current population of children, with the most recent NHANES III data. Uncertainties about BW estimates also affect SA estimates because SA correlates with BW, and these uncertainties occur in addition to uncertainties about the relationship used for the estimation.

For many assessments of dermal exposure, analysts need to consider the extent to which different parts of the child's body may be exposed as a function of different activities or behavior, which may involve asking adults to provide data on a child's behalf.[27] For example, consider a child wearing shorts who sits in the sand to play, or a child who is crawling and pulls his or her legs and hands over the floor. The fact that children exhibit different behaviors as they grow may have an impact on the estimates of exposure, and the correlation of exposed body area with activities may be very important in some cases.

6. Changes in Ingestion and Mouthing Behavior

Assessing exposure from ingestion is probably the most difficult of all the exposure routes because so many things are ingested or mouthed. Initially, children consume large amounts of breast milk or formula and then gradually their diets become increasingly more varied. National dietary studies, including the US Department of Agriculture (USDA) Nationwide Food Consumption Survey (NFCS) and Continuing Survey of Food Intakes by Individuals (CSFII),[28] provide a large amount of information about dietary exposure. The data collected in these large studies are generally reported in age-range categories and they are available for reanalysis. These studies are typically cross-sectional in nature and capture variability in the population well, at least at the time of the survey, but they do not capture longitudinal changes in dietary-consumption patterns for individual children as they grow. This lack of longitudinal data makes the assessment of lifetime aggregate exposure challenging, particularly with respect to understanding the important sources of correlation. For example, do children who eat a relatively large amount of grapes as 9-month-olds continue to consume a lot of grapes into their teens? Is eating a lot of grapes more characteristic of a phase or parental concepts about what young children should eat? Do children who consume a lot of apples also eat a lot of pears? These types of questions are difficult to answer with the available data.

Section 6 reviews 6 key exposure factors concerning ingestion in children:

- Section 6.1 reviews the age categories used in the 1 major survey that assesses *food intake* amounts.
- Section 6.2 covers *drinking water ingestion*, for which data are available from several large studies.
- Sections 6.3 and 6.4 review the age-category information in the ingestion-exposure databases for *breast milk* and *fish*, respectively. These databases are based on much smaller studies in local populations.
- Finally, several small studies provide some information about nondietary ingestion exposures of children. These studies generally do not include national data, but instead report the results for a small convenience sample of children studied in a specific local area. Typically, the categories used for children in the smaller studies represent the age ranges of the children in the study. Although the data may be accessible by contacting the researchers who conducted the study, given the relatively small sample sizes involved, reassessing them to look at different age categories is less likely to be useful than for some of the larger national studies. Nonetheless, Sections 6.5 and 6.6 review the age-category information for *soil ingestion* and *for mouthing nondietary objects*, respectively.

6.1. Food Intake (IR_{food}/BW)

Table 3 summarizes the age groupings for food intake provided by the USDA's CSFII study, which provides data from a national survey of food consumption.[28] The results include data for total fruits, vegetables, grains, meats, fish, dairy products, and fats. USDA collects these national data with a stratified sampling strategy that specifically collects food-consumption information from children. The data are reported as daily intake rates per unit of BW (g of food/kg of BW/day) (ie, data were collected for each individual so the reported data preserve the correlation between food consumption and BW). Thus, no additional calculation is needed to account for BW when estimating dose. The food-intake factor comes from Equation 5, and it relates to the W_T factor mentioned by Cohen Hubal and colleagues[4] and given in Equation 4 (when the W_T is multiplied by the number of such food items consumed per day [N] and divided by BW).

Unfortunately, the USDA data do not provide information over long time periods, nor has USDA collected longitudinal data for individual children. For a "typical child," there are some long-term dietary constraints that must apply (eg, requirements for caloric intake and sufficient vitamins and minerals). However, the extent to which individual children meet these requirements is unknown. A correlation of diet with socioeconomic factors may also be an important issue in the context of the exposure and risk assessment, but this is difficult, although not impossible, to do quantitatively with the existing data.[29]

6.2. Drinking Water Consumption (IR_{water} or IR_{water}/BW)

Several large studies on drinking water intake provide good estimates of the amount of drinking water consumed with their age groupings for drinking water consumption summarized in Table 4. Not surprisingly, the amount of drinking water consumed may depend on the type of physical activity being done by the individual and on the temperature and humidity (eg, people typically consume more water in the summer). The existing studies provide information about both the total tap water consumed and the total fluid intake. The data from these surveys are generally available for reanalysis, and analyses aimed at characterizing the variability in the population suggest that the data appear to distribute lognormally.[31] Recently, another study reported on tap water intake of pregnant and lactating women as young as 15 years of age.[32]

6.3. Breast Milk ($IR_{breastmilk}$)

Five studies provide estimates of breast milk intake that can be used to estimate infant exposure to substances in the milk. Table 5 summarizes the age groupings for breast milk data from these studies, which included estimates of infants up to age 1 (ie, no data are available for children who are breast-fed beyond age 1). Most of the studies have focused on quantifying milk ingestion for young infants (under 6 months).

Information about the percentages of infants who are breast-fed is relatively sparse.[39] However, a recent study[40] provides data for the percentage of newborns and 6-month-old infants being breast-fed, and these data suggest that breast-feeding rates increased between 1989 and 1995. To estimate a population risk (or population exposure) for this exposure pathway, additional information about breast-feeding practices may be needed to address the impacts of major social changes, including shorter postpartum hospitalization for normal deliveries, longer infant hospitalization for very premature infants, different perceptions of the value of breast-feeding that may have an impact on the amount of breast milk consumed, the tendency of mothers to breast-feed, and the age at which babies are weaned.

6.3. Fish Consumption (IR_{fish})

Amounts of fish consumed depend on the segment of the population under consideration. For children in some segments of the population, data about the amount and types of fish eaten are relatively sparse. In particular, people who catch fish, either for sport or for sustenance, are generally likely to consume more fish than those people who do not. Does this tendency translate to greater fish consumption for their children? For those fishing for sustenance, it probably does, but for sport fishers it may not. In either case, few data are available to answer these questions.

Because different population segments consume different types and amounts of fish, the data for fish consumption cover several different categories of fish consumed and types of consumers. Table 6 summarizes the age groupings for fish consumption. Although general intake data are available from USDA's large CSFII database,[28] most of the fish-consumption data come from relatively small studies. These data are difficult to extrapolate to the larger population and make the characterization of variability a challenge. The age categories used in the studies differ, and very little information is available at all for fish consumption by relatively young children. These data are not as readily accessible as the data from the national surveys, but they have been reassessed to characterize variability in some cases.[48]

6.5. Soil Ingestion (IR_{soil})

The amount of soil ingested by children depends on whether or not the ingestion is intentional:

- For incidental ingestion, several studies have attempted to measure soil intake indirectly by measuring the amounts of trace elements in stool and urine samples, and in some studies by subtracting the amounts of these elements in food (with duplicate meals); and
- Very limited exposure data are available for intentional ingestion of soil, known as pica.

Table 7 summarizes the age groupings for the soil-ingestion data. The methodology used to estimate soil ingestion is indirect, relatively complicated, and prone to errors leading to a significant amount of uncertainty about the amount of soil ingested by children. The studies reflect short-term, small local analyses that do not extrapolate easily to national, long-term studies. In addition, soil-ingestion tendencies probably vary considerably over days, and characterization of this variability is relatively limited[55] as is the extent to which children ingest soil as a function of different mis. As discussed by Cohen Hubal and colleagues[4] and shown in Equation 4, 1 mechanism for soil ingestion is when children eat with dirt on their hands that gets transferred to the food, or when food drops onto a dirty surface and children pick it up and eat it. The existing soil-ingestion data do not distinguish among the different activities that lead to soil ingestion, and more effort is needed to combine activity monitoring/modeling with amounts of soil ingested.

Also, remarkably, the existing studies do not include children under age 1 year, even though these children are likely to be in contact with the floor, and consequently more data for this age group of young children are needed. Data for children over age 7 years are also missing, and although this behavior is likely to be reduced significantly by age 7 years, some soil ingestion may continue beyond that age associated with normal outdoor play.

6.6. Other Nondietary Ingestion

Children may be exposed to environmental pollutants when they place nonfood items into their mouths, as discussed for Equation 6. The studies regarding this behavior tend to be divided into studies that estimate the duration of mouthing

(T_{mouth}) and studies that estimate the frequency of mouthing (EF). Although these are related concepts, they are not the same, and slightly different equations are needed to estimate exposure on the basis of these different data.

Table 8 summarizes the age groupings for non-dietary-ingestion data. In general, the link between the duration of mouthing and mis or mas is relatively unexplored. The studies included here represent very small, nonnational studies that are typically of a short duration. The mouthing duration data collected by Juberg and associates[58] suggest that longitudinal studies of mouthing duration are needed because regression to the mean does occur and children's mouthing duration of objects does decrease over the first 3 years. No studies provide information about mouthing behavior for children over age 6. Although this behavior is likely to be reduced significantly by age 6 years, some mouthing of objects may continue beyond that age associated with outdoor play, consumption of candy, and adolescent smoking. No information also exists related to the attributes of objects that make them relatively more or less attractive to children for mouthing. For example, are children more likely to mouth nonfood objects that look and/or smell like food, or do children mouth objects of certain colors more than objects of other colors?

7. Inhalation (IR_{ma})

A number of studies provide data on inhalation rates for children. Inhalation rates vary as a function of activity (ie, higher-than-average ventilation rate when exercising, lower when sleeping), and estimates are available for several different types of activities for both healthy and asthmatic children. Table 9 summarizes the age groupings for the inhalation data.

The estimates by Layton[67] rely on assessing inhalation rates on the basis of food-energy intake and on basal metabolic rate. Because dietary data are available for large numbers of people, the sample sizes possible with this approach can be very large. However, because a model is required to go from the food-intake to the inhalation-rate estimate, error may be introduced into the estimates associated with the model. Although Layton[67] found similar estimates of inhalation rates with different data and modeling approaches and this provides some confidence of the robustness of the findings, some uncertainties remain about the results. In addition, different age categories were used because of differences in the age categories in the input data for the models.

One challenge in using the inhalation-rate data is the need to characterize the daily activities to obtain good estimates of the average daily inhalation rate. Exposure and risk assessors typically want to know the inhalation rate over a longer time period than simply during an activity, so some time/activity weighting is needed to meet the needs of risk analysts. Remarkably, none of the studies report inhalation rate as a function of BW or address their correlation. Studies with longitudinal data on inhalation rates are missing, and additional studies are needed to better characterize the inhalation rates of children as a function of age and to estimate their average inhalation rates.

8. Dermal Contact

In contrast to many other exposure factors for which daily rates are common and generally available, the available data for dermal contact are primarily activity-based, and consequently standard default recommendations do not exist.[3] Instead, analysts typically must find the activity that is most similar to the 1 of interest and estimate the dermal soil loading by analogy.

Table 10 summarizes the age groupings for the rate of soil adherence to the skin as a function of different activities on the basis of controlled experiments. The relatively small database leaves a high degree of uncertainty in the estimation of dermal exposure and provides only a limited ability to characterize variability in the population. In addition, the observations made in the field studies may not be fully representative of the actual activities that occur. As a result of the design of these studies, the age ranges reported reflect the age ranges of the participating subjects. In some analyses of dermal exposure, knowing the SA of the body or part of the body may be necessary (see Section 5.2).

One factor that may have an impact on the amount of skin in contact with contaminants is the amount of clothing worn by the individual for various activities. Seasonal variations are likely to affect both the activities and the clothing worn, and data that account for this correlation are not currently available for children, although the data sources for Table 10 do note the types of clothing worn by participants and the month of the data collection. Given the limitations in the number of mes and activities for which the data are available, additional data may be needed to better characterize dermal contact.

9. Time/Activity Patterns ($T_{me/ma}$)

Several national and local studies provide data on how children of various ages spend their time in various mes and on various major activities. Table 11 summarizes the age groupings for the time/activity pattern data. In some cases,[4,74] data were reanalyzed to assess the variability in the population for some factors, and this means that the data listed in Table 11 are not independent. Exposure assessors may also want information about the level of activity or exertion, and 1 study provides information with the categories quiet, medium, and active.[75]

One issue associated with time/activity is the need to meet the constraint of 24 hours/day when combining data. This issue has not been thoroughly addressed in the context of children's exposure estimates or in the characterization of variability in time/activity patterns. In particular, if times spent tend to distribute lognormally, then the means will exceed the medians and adding the mean values could lead to average time/activity estimates that exceed 24 hours/day. Analysts need to develop appropriate multivariate distributions of times in (micro)environments to ensure that the restriction of 24 hours/day is preserved when combining activity/environmental data.

Similar to other factors, no longitudinal studies exist, and all of the time/activity data require extrapolation from the short term to the long term, which suggests the need for additional study.

10. Discussion

As demonstrated in Sections 5-9, substantial exposure information is available, but significant gaps in our knowledge still remain. The representativeness of available data and the lack of data in key areas pose challenges to exposure and risk assessors for children's health, and they should be considered in any future data-collection efforts (eg, the potential National Children's Study).

For all the exposure factors discussed, the representativeness of the available data to the individual, population, temporal, and/or spatial scale of interest remains an ongoing issue. Not surprisingly, we know the most about children's observable anatomic characteristics, such as BW and height, and we know the least about less easily observable behavioral characteristics, such as where and how they spend their time or how much soil they ingest. Nonetheless, even in the area of anatomic development in which we have substantially more data, issues of representativeness pose challenges for exposure and risk assessors. For example, we have limited information about how well measurements collected for today's children will represent children of future generations. Further, with advances in medical technologies, significant numbers of low birth weight babies (less than 2500 g) and very low birth weight babies (between 1000 and 2500 g) now survive, and essentially no exposure assessment information exists for these children.

Extrapolation from today's children to future generations also raises challenges for exposure and risk assessors in the context of behavioral changes. For example, eating habits and practices change so dramatically that studies of eating habits from 10 years ago might not mention foods that children eat today (eg, new breakfast cereals and exotic foods). In addition, with the increased globalization of trade, today's children can eat "seasonal" fruits and vegetables nearly all year.

With respect to using a microenvironment, macroactivity, and microactivity approach in exposure models, the data are somewhat limited in some contexts to support these efforts. Table 12 summarizes the different factors discussed in Sections 5 through 9 and indicates which of the exposure equations listed in Section 3 use that factor. Note that overall body SA, the number of fish meals ($N_{fishmeals}$), and the duration of mouthing of objects (T_{mouth}) are not listed in Equations 1 through 7, but they are required in some cases (eg, as indicated in the sentence that follows Equation 4, information about $N_{fishmeals}$ is required to convert the exposure estimate from Equation 4 into appropriate units). Using these factors requires modification of the exposure equations or modification of the factor to be consistent with the equations.

Table 13 lists the exposure factors that were not discussed in Sections 5 through 9 that are required in Equations 1 through 7. Note that Equations 3 and 4, in particular, require many of these factors for which no data are available. These factors indicate some of the challenges that analysts will face in using Equations 3 and 4, given the existing data. The presence of the transfer coefficients (DTC and TEs) in Table 13 is not surprising because, like concentrations, these values are substance-specific, and analysts have undertaken research efforts to collect these data when needed. However, comparing Tables 12 and 13 clearly shows that very little data exist related for nondietary intake. In particular, how does the way that children handle food have an impact on their exposure? What is the amount of a contaminant that can be ingested from food items retrieved from the floor, and in what contexts do these exposures matter?

A comparison of the consistency of age categories used across the studies reviewed indicates that some important differences in age categories exist for the individual equations used to estimate exposure and dose. For analysts attempting to estimate aggregate exposure (multiple pathways for the same substance), the consistency of the age categories for the data used in different equations may also be an issue. In general, the lack of longitudinal data that would allow correlation of the exposure with growth limits the ability to confidently model children's exposure. For example, when modeling aggregate exposure as required by the Food Quality Protection Act, analysts face the challenges of building long-term exposure profiles on the basis of short-term data from a wide range of sources. In this context, they must make assumptions about the interindividual variability (ie, the extent to which the observed differences in daily exposures represent differences between children) and the intraindividual variability (ie, the extent to which the observed differences in daily exposures represent differences for each child). In reality, both sources of variation exist, and our ability to characterize them is limited by the lack of repeated samples in longitudinal studies. Nonetheless, the aggregate exposure models that analysts developed to meet the demand of the FQPA have implemented strategies to deal with these issues in the absence of complete information (see the literature for a recent review of these models[76]).

Although the data are limited, the demand for exposure and risk analysis to inform risk-management decisions concerning children's health continues to increase. For most of the exposure factors discussed in this article, some information is available, and analysts should find sufficient data to support a qualitative assessment of the value of obtaining better exposure information in the context of the overall uncertainty. Significant data gaps remain in the following areas:

- Breast-milk consumption by infants today and for children over age 1 year;
- Children's food-handling practices and how this leads to exposure (eg, by eating with dirty hands or by eating food that has dropped onto a contaminated surface);
- Fish-intake rates for young children and for children whose families include sport fishers or whose families rely on self-caught fish for sustenance;
- Incidental and intentional soil intake by children;
- Soil adherence for dermal exposure;
- Relationships between various microenvironments, macroactivities, and microactivities where children spend time;
- Correlation between exposure factors and growth (ie, how children's exposure behaviors change over time); and
- Longitudinal data needed to track exposures over time and to assess the impacts of early exposure and/or events on children's developmental trajectories.

The demand for aggregate exposure assessment and cumulative risk assessment under the Food Quality Protection Act created a much greater need for information about correlation between exposure factors and growth and placed emphasis on the combined exposures that children experience instead of exposure from a single pathway. This naturally leads to interest in better characterizing children's exposure in all contexts, not limited to pesticide residues. Currently, the greatest challenge lies in combining the data from various independent studies in a way that appropriately models the experiences of real children. In some cases in which data do exist, we may also come to appreciate that more information is still required. For example, although data provide good information about the time spent at home by age category, they do not provide extensive information about the activities pursued while at home. In addition, very little information exists about the details of how time is spent in different mes, although videography studies and other new methods provide a means for collecting these data.[54,77] In addition, how school-age children spend their time in summer months and after school remains relatively uncertain.

A large, national longitudinal study of children's exposure would provide valuable data to support exposure and risk analyses. However, currently enough information does exist to support modeling efforts as long as the uncertainty in the analysis is appropriately considered. In the context of the value of the information that exists now, the most significant challenge for modelers comes from extrapolating the existing data from the short term to the longer term, a data need that can only be effectively addressed with a large longitudinal study, such as the National Children's Study. Analysts should conduct quantitative value of information analyses to quantify the benefits of obtaining additional data with existing methodology[78,79] to demonstrate the expected economic benefits obtained by basing societal decisions on better information.[80] In the context of investments in data collection for protecting children from health risks associated with exposure to substances in their environments, efforts to prioritize resource allocation should also consider the overall uncertainty (ie, including uncertainty about dose response, economic assessments, etc) and the decision-making context.[81,82]

Key of Symbols:	
BW =	body weight (kg)
SA =	area of surface that is contacted (cm^2/event)
$SA_{S/F}$ =	area of food item in contact with contaminated surface (cm^2/event)
$SA_{H/F}$ =	area of food item in contact with contaminated hand (cm^2/event)
SA_x =	area of object x or hand that is mouthed (cm^2/event)
IR_{food} =	the amount of the specific food that the child consumes in a day (g/day) (general category includes breast milk, drinking water, fish, etc)
W_T =	amount of the individual food consumed (g/food item)
TE =	transfer-efficiency fraction transferred from surface to skin (unitless)
$TE_{S/F}$ =	transfer-efficiency fraction transferred from surface to food (unitless)
$TE_{H/F}$ =	transfer-efficiency fraction transferred from hand to food (unitless)
TE_{xm} =	transfer-efficiency fraction transferred from object x or hand to mouth (unitless)
EF =	frequency of contact event over a 24-hour period (events/day)
$EF_{S/F}$ =	frequency of surface-to-food contact events that occurs during consumption of food item (events/food item)
$EF_{H/F}$ =	frequency of surface-to-food contact events that occurs during consumption of food item (events/food item)
IR_{ma} =	the child's respiration rate representing his activity level for that macroactivity (m^3/hour)
DSL =	dermal soil loading on surface (mg/cm^2)
DTC_{der} =	dermal-transfer coefficient for the microenvironment/macroactivity (cm^2/hour)
$T_{me/ma}$ =	the time spent in that microenvironment/macroactivity during the 24-hour period (hour/day)

Tables

Table 1. Key Body Weight Data Sources and Age Categories Used

Description	Data Sources	Age Groups Used for Reporting Data	Quality and Value of Information
Body weight	3,19*	2 months (n = 243) 3 months (n = 190) 2-6 months (n = 1020) 7-12 months (n = 1072) 1 year (n = 1258) 2 years (n = 1513) 3 years (n = 1309) 4 years (n = 1284) 5 years (n = 1234) 6 years (n = 750) 7 years (n = 736) 8 years (n = 711) 9 years (n = 770) 10 years (n = 751) 11 years (n = 754) 12 years (n = 431) 13 years (n = 428) 14 years (n = 415) 15 years (n = 378) 16 years (n = 427) 17 years (n = 410)	Quality = high Value of information = high
Body weight	3,18	6-11 months (n = 356) 1 year (n = 706) 2 years (n = 711) 3 years (n = 784) 4 years (n = 800) 5 years (n = 761) 6 years (n = 268) 7 years (n = 305) 8 years (n = 270) 9 years (n = 294) 10 years (n = 293) 11 years (n = 295) 12 years (n = 292) 13 years (n = 335) 14 years (n = 364) 15 years (n = 329) 16 years (n = 348) 17 years (n = 307) 18 years (n = 334) 19 years (n = 306)	

**Data from source 16 are still becoming available, and not all of the sample size numbers were available at the time that the author most recently accessed the data. However, this data source provides 3rd, 5th, 10th, 25th, 50th, 75th, 90th, 95th, and 97th percentiles, means, and standard deviations of body weight for boys and girls as a function of monthly age up to 36 months and as a function of age in years for children between 2 and 20 years old. The sample size numbers reported here correspond with those found in the literature.*[2]

Table 2. Surface Area Data Sources and Age Categories Used

Description	Data Sources	Age Groups Used for Reporting Data	Quality and Value of Information
Surface area	3,25	2-3 years 3-4 years 4-5 years 5-6 years 6-7 years 7-8 years 8-9 years 9-10 years 10-11 years 11-12 years 12-13 years 13-14 years 14-15 years 15-16 years 16-17 years 17-18 years	Quality = medium Value of information =medium (based on extrapolation with relativelyold data, inadequate information for children under age 2)
Surface area/ body weight ratio	26	0-2 years 2.1-17.9 years	

Table 3. Food-Intake Data Sources and Age Categories Used

Description	Data Sources	Age Groups Used for Reporting Data	Quality and Value of Information
Food intake (for various foods)	3,28	< 1 year (n = 359) 1-2 years (n = 1356) 3-5 years (n = 1435) 6-11 years (n = 1432) 12-19 years (n = 1398)	Confidence = high in average, low in long-term, upper percentiles Value of information = medium (lack of long-term data)

Table 4. Drinking Water Data Sources and Age Categories Used

Description	Data Sources	Age Groups Used for Reporting Data	Confidence and Value of Information
Drinking water intake for total fluid intake (IR_{water} and IR_{water}/BW)	3,28,30	0 < 1 year (n = 359) 1-10 years (n = 3980) 11-19 years (n = 1641)	Confidence = high Value of information = high
Drinking water intake for total fluid intake (IR_{water} and IR_{water}/BW)	3,28,30	< 0.5 (n = 199) 0.5-0.9 (n = 160) 1-3 (n = 1834) 4-6 (n = 1203) 7-10 (n = 943) 11-14 (n = 816) 15-19 (n = 825)	

Table 5. Breast Milk Ingestion Data Sources and Age Categories Used

Description	Data Sources	Age Groups Used for Reporting data	Confidence and Value of Information
Breast milk intake	33	Completely breast-fed 1 month (n = 11) 3 months (n = 2) 6 months (n = 1) Partially breast-fed 1 month (n = 4) 3 months (n = 11) 6 months (n = 6) 9 months (n = 3)	Confidence = medium Value of information = low (based on small sample size and inability to characterize variability)
Breast milk intake	34	1 month (n = 16) 2 months (n = 19) 3 months (n = 16) 4 months (n = 13) 5 months (n = 11) 6 months (n = 11)	
Breast milk intake	35	1 month (n = 37) 2 months (n = 40) 3 months (n = 37) 4 months (n = 41)	
Breast milk intake	36	Intake per day Each day for days 1-11 (n = 7-12) For days 14, 21, 28, 35, 42, 49, 56 (n = 10-13) For days 90, 120, 150, ..., 360 (n = 9-13)	
Breast milk intake	37,38	3 months (n = 73) 6 months (n = 60) 9 months (n = 50) 12 months (n = 42)	

Table 6. Fish-Intake Data Sources and Age Categories Used

Description	Data Sources	Age Groups Used for Reporting data	Confidence and Value of Information
General intake rates (freshwater and estuarine, marine, and total) (IR_{fish} and IR_{fish}/BW)	41 (Data from ref. 28)	14 or under (n = 2977) 15-44 years (n = 5042)	Confidence = high in average, low in long-term upper percentiles Value of information = medium (some data relatively old)
General intake rates of fish consumers (IR_{fish})	42	0-9 years 10-19 years	
General intake rates of fish consumers (freshwater finfish, saltwater finfish, and shellfish) (IR_{fish})	43	< 11 years 12-18 years 19+ years	
Fish meals per month for anglers with fishing licenses (IR_{fish} and IR_{fish}/BW and $N_{fish\ meals}$)	44,45	1-5 years 6-10 years 1-20 years	
Intake rate for Native American fishers (IR_{fish})	46	< 5 years (n = 204)	
General number of fish eating events (meals) ($N_{fish\ meals}$)	47	1-4 years 5-11 years 12-17 years	

Table 7. Soil-Ingestion Data Sources and Age Categories Used

Description	Data Sources	Age Groups Used for Reporting data	Confidence and Value of Information
Soil intake -- nonintentional (IR_{soil})	49	1-3 years (n = 65)	Confidence = medium for average, long-term central estimates Value of information = low (all non-national data, short-term studies, not all ages of children included) High
Soil intake -- nonintentional (IR_{soil})	50	2-4 years (n = 18)	
Soil intake -- nonintentional (IR_{soil})	51	1-4 years (n = 64)	
Soil intake -- nonintentional (IR_{soil})	52	2-7 years (n = 104)	
Soil intake -- nonintentional (IR_{soil})	53	1-5 years (n = 292)	
Soil intake (pica) (IR_{soil})	54	3.5 years (n = 1)	

Table 8. Non-Dietary-Ingestion Data Sources and Age Categories Used

Description	Data Sources	Age Groups Used for Reporting data	Confidence and Value of Information
Duration of mouthing (T_{mouth})	56	1. months (n = 5) 6-12 months (n = 14) 12-18 months (n = 12) 18-36 months (n = 11)	Confidence = low Value of information = low for long-term central estimates and for all extremes
Duration of mouthing (T_{mouth})	57	10-60 months (n = 92)	
Duration of mouthing (T_{mouth})	58	0-18 months (n = 275) 19-36 months (n = 110)	
Frequency of mouth contact (EF)	59	3-13 years (n = 19)	
Frequency of mouth contact (EF)	60	2-6 years (n = 30)	
Frequency of mouth contact (EF)	61	2.5-4.2 years (n = 4)	
Frequency of mouth contact (EF)	62	23-33 months (n = 3)	
Frequency of mouth contact (EF)	63	2-6 years (n = 10)	

Table 9. Inhalation-Rate Data Sources and Age Categories Used

Description	Data Sources	Age Groups Used for Reporting data	Confidence and Value of Information
Inhalation rate of healthy and asthmatic youth	64	10-12 years (n = 17) 13-17 years (n = 19) 11-16 years (n = 13)	Confidence = medium Value of information = medium (limited data for very young children, small sample sizes)
Inhalation rate of healthy youth exposed to oxidant pollution	65	10-12 years (n = 17) 13-17 years (n = 19)	
Inhalation rate for "young children" (3-5.9), "children" (6-13)	66	3-5.9 years 6-12.9 years	
Inhalation rate estimated based on food energy intake	67	< 1 years 1-2 years 3-5 years 6-8 years 9-11 years 12-14 years 15-18 years	
Inhalation rate estimated based on basal metabolic rate	68	0.5 to < 3 years 3 to < 10 years 10 to < 18 years	

Table 10. Soil-Adherence Data Sources and Age Categories Used

Description	Data Sources	Age Groups Used for Reporting data	Confidence and Value of Information
Soil adherence from 1.5 hours of indoor Tae Kwon Do	68,69	8-42 years (n = 7)	Confidence = low Value of information = low (data are very limited, but active research efforts underway are providing more information for specific substances with important dermal pathways)
Soil adherence from 2 hours of indoor play on carpeted floor	68,69	6-13 years (n = 4) 3-13 years (n = 6)	
Soil adherence from indoor and outdoor exposure during day care (4 groups of children in day care 3.5, 4, 8, and 8 hours, respectively)	68,69	1-6.5 years (n = 6) 1-6.5 years (n = 6) 1-4 years (n = 5) 1-4.5 years (n = 4)	
Soil adherence from 0.67 hours of outdoor soccer	68,69	13-15 years (n = 8)	
Soil adherence from 4 hours of outdoor gardening	68,69	16-35 years (n = 8)	
Soil adherence from 11.5 hours of archaeological work	68,69	16-35 years (n = 7)	
Soil adherence from kids playing in mud (2 times for 0.17 and 0.33 hours, respectively)	68,69	9-14 years (n = 6)	

Table 11. Time/Activity Pattern Data and Age Categories Used

Description	Data Sources	Age Groups Used for Reporting data	Confidence and Value of Information
Average time spent for major activities	70	3-11 years (n = 229) 12-17 years (n = 160)	Confidence = medium Value of information = medium (data are limited for infrequent activities, but do allow good characterization of major activities)
Average time spent for major activities	70	3-5 years 6-8 years 9-11 years 12-14 years 15-17 years	
Average time spent indoors, outdoors, in vehicle, and in various activities	71	< 12 years	
Average time spent in various microenvironments	71	12-17 years (n = 183) 18-24 years (n = 250)	
Average time spent in various major activities	72	0-2 years (n = 313) 3-5 years (n = 302) 6-8 years (n = 269) 9-11 years (n = 316)	
Average time spent in various activities	73	5-9 years (n = 300) 10-12 years (n =196)	
Average time spent at home and away from home and level of activity with respect to inhalation exposure	74	6-8 years (n = 269) 9-11 years (n = 316) 12-17 years (n = 183)	
Average time spent in various activities	4	0 years (n = 199) 1 year (n = 238) 2 years (n = 264) 3 years (n = 242) 4 years (n = 232) 5 years (n = 227) 6 years (n = 199) 7 years (n = 213) 8 years (n = 226) 9 years (n = 195) 10 years (n = 199) 11 years (n = 206)	
Average time spent indoors and outdoors at home and away from home	52	10-60 months (n = 92)	
Average time spent showering, in the bath, or in the bathroom	47	1-4 years (n = 40) 5-11 years (n = 139) 12-17 years (n = 268)	
Percentage of time at level of exertion	75	9-11 years (n = 91) 15-17 years (n = 42)	

Table 12. Summary of Physiologic and Behavioral Factors Discussed in Sections 4 Through 8

Factor	Confidence (From Ref. 3)	Value of Information	"X" Denotes Used in Equation Number						
			1	2	3	4	5	6	7
BW	H	H							X
SA SA/BW	M	M							
IR_{food}/BW	H/L	M					X		
IR_{water} IR_{water}/BW	H	H					X		
$IR_{breastmilk}$	M	L					X		
IR_{fish} IR_{fish}/BW	H/L	M					X		
$N_{fish\ meals}$	H/L	M							
IR_{soil}	M	L					X		
T_{mouth}	L	L							
$EF_{mouthing}$	L	L						X	
IR_{ma}	M	M	X						
DSL	M	L			X				
$T_{me/ma}$	M	M	X	X					

Table 13. Summary of Other Exposure Factors

Factor	"X" Denotes Used in Equation Number						
	1	2	3	4	5	6	7
DTC_{der}		X					
EF_{dermal}			X				
TE_{dermal}			X				
SA_{dermal}			X				
W_T				X			
$TE_{S/F}$				X			
$EF_{S/F}$				X			
$SA_{S/F}$				X			
$TE_{H/F}$				X			
$EF_{H/F}$				X			
$SA_{H/F}$				X			

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