APPENDIX H

CHANGES IN CHILDREN'S EXPOSURE AS A FUNCTION OF AGE AND THE RELEVANCE OF AGE DEFINITIONS FOR EXPOSURE AND RISK ASSESSMENT (PAPER DISTRIBUTED AT WORKSHOP BY KIMBERLY THOMPSON)

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

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1. Introduction

During the past decade, improving the lives of children has emerged as a priority on the national agenda. In the public and environmental health arena, this priority has been reflected in changes to statutory requirements (e.g., the 1996 Food Quality Protection Act and the Safe Drinking Water Act) and in President Clinton's Executive Order 13045. This Executive Order requires 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" (EO13045, 1997). The Food Quality Protection Act creates a demand for estimating aggregate exposure (i.e., estimating exposure from multiple pathways for the same substance) and cumulative risk (i.e., assessing the risk of all substances that act with same mechanism of toxicity over all the multiple pathways in which they may act).

The focus on children's health raises many challenges for exposure and risk analysts. Children are in a distinct phase of human life with unique characteristics that distinguish them from adults. From birth to adulthood their physiology and behavior are constantly evolving, making them a "moving target" for exposure and risk assessment. This raises a number of issues:

- 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 it is the most appropriate way to estimate childhood exposure given the limitations in currently available exposure information?
- To what extent is further research needed to provide the data necessary for estimating children's exposure? What short-term studies or longer-term research are needed to provide the missing data?

This issue paper has been prepared to stimulate discussion on these issues, with a particular focus on age-related anatomical and behavioral changes in children (changes in pharmacokinetics and pharmacodynamics are not covered). The paper synthesizes the most current and relevant information regarding children's anatomical and behavioral changes and discusses their value in exposure and risk assessment. The paper is organized as follows:

- Section 2 reviews some of the key issues regarding children's exposure and risk assessment.

- Section 3 presents a series of equations, developed Hubal et al. (2000) that provide a useful approach for estimating exposure in children. 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. A Child-Specific Exposure Factors Handbook (CSEFH) currently being developed by the U.S. Environmental Protection Agency (EPA) will provide additional information to analysts about the inputs in these equations. (Note that the handbook will offer recommended values for exposure factors based on existing data, but will not specify exposure factors as a function of particular ages or age ranges.)
- Sections 4 through 8 of this paper synthesize and discuss the available data (as provided in EPA's Child-Specific Exposure Factors Handbook) for each of the child-based exposure factors utilized in Hubal et al.'s equations.
  - Section 4 discusses on anatomical changes that occur during growth (i.e., body weight and skin surface area).
  - Sections 5, 6, 7, and 8 discuss behavioral factors related to ingestion (food intake, drinking water consumption, breast milk, fish consumption, soil ingestion, and other non-dietary exposure factors); inhalation; dermal exposure; and time-activity patterns, respectively.
- Finally, Section 9 characterizes the challenges and constraints that analysts face when using these data in exposure and risk assessments.
- References are listed in Section 10.

2. Key Issues for Children's Exposure

2.1 Unique Characteristics of Children

Children experience remarkable change from birth to adulthood. Two of the most dramatic changes are rapid increases in weight and height. Figures 1a-1d summarize the increase in height and weight for each gender up to age 3 and for ages 3-18 (note that these show continuous functions fit to cross-sectional discrete data to show the continuity of growth). Figure 2 shows the changes in body proportions that occur from age 2 months to adulthood.

In addition to physical growth, children pass through numerous other physiological, psychological, social, and behavioral phases. These phases have different duration. Figure 3 shows a typical chart for normal developmental milestones. Note that milestones for fine motor, gross motor, language, and personal or social development are categorized separately. Also note that these charts do not include anatomical changes such as teething that could impact 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 (e.g., kids with fair skin), while others may depend on child-specific activity patterns (e.g., children that swim, children that consume a lot of a particular food, teenage girls that wear make up).

Figure 1(a): Growth chart for girls birth to 3 years.
(Source: http://www.ama-assn.org/insight/h_focus/nemours/baby/grow.htm)

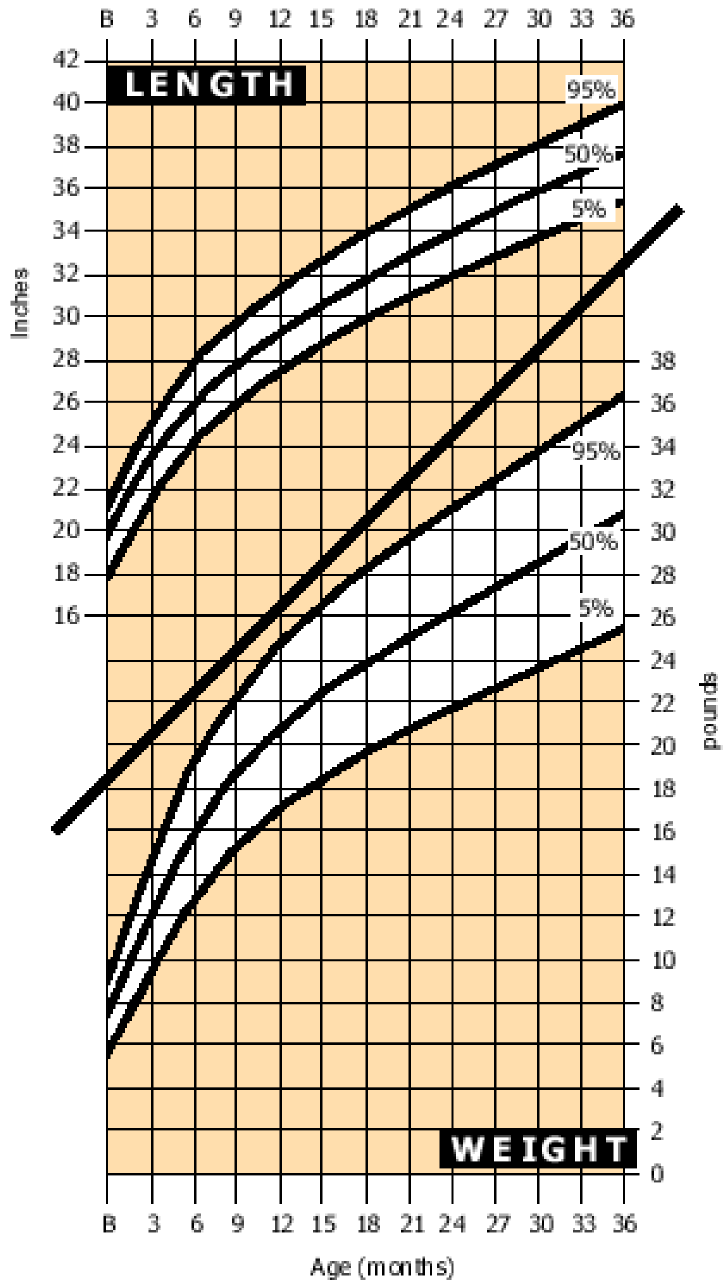


Figure 1(b): Growth chart for boys birth to 3 years.
(Source: http://www.ama-assn.org/insight/h_focus/nemours/baby/grow.htm)

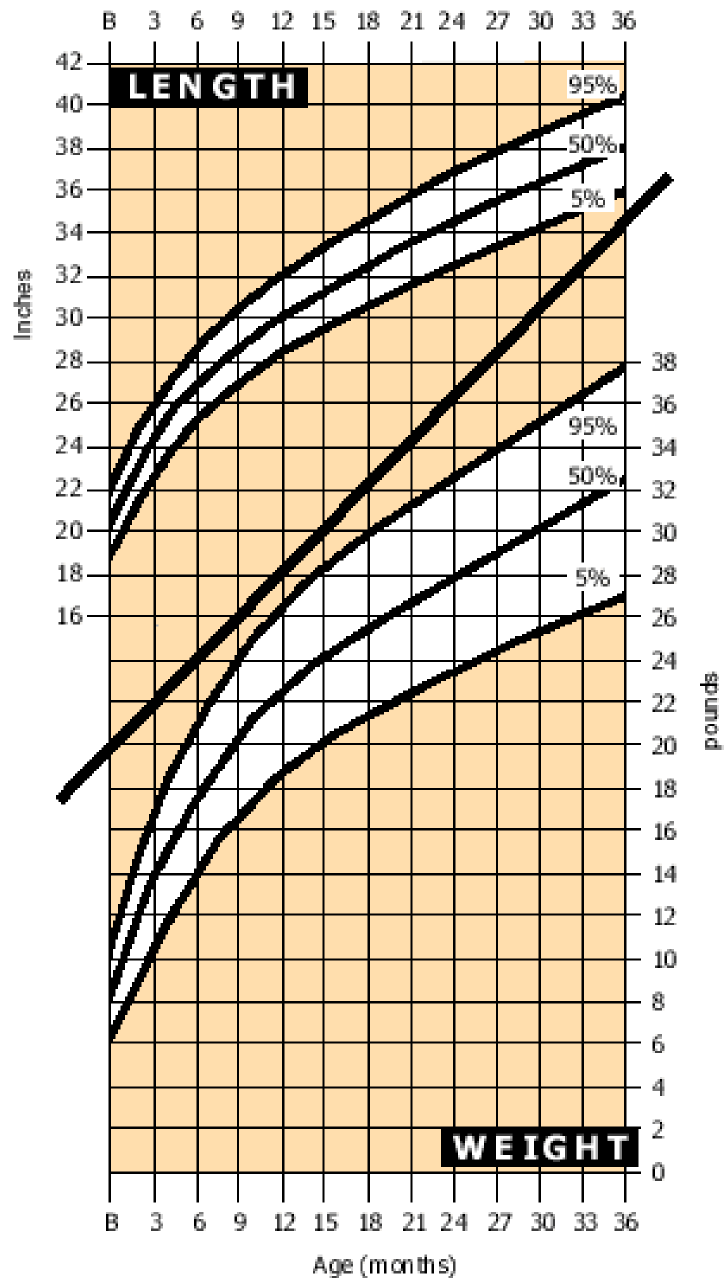


Figure 1(c): Growth chart for girls 3 to 18 years.
(Source: http://www.ama-assn.org/insight/h_focus/nemours/baby/grow.htm)

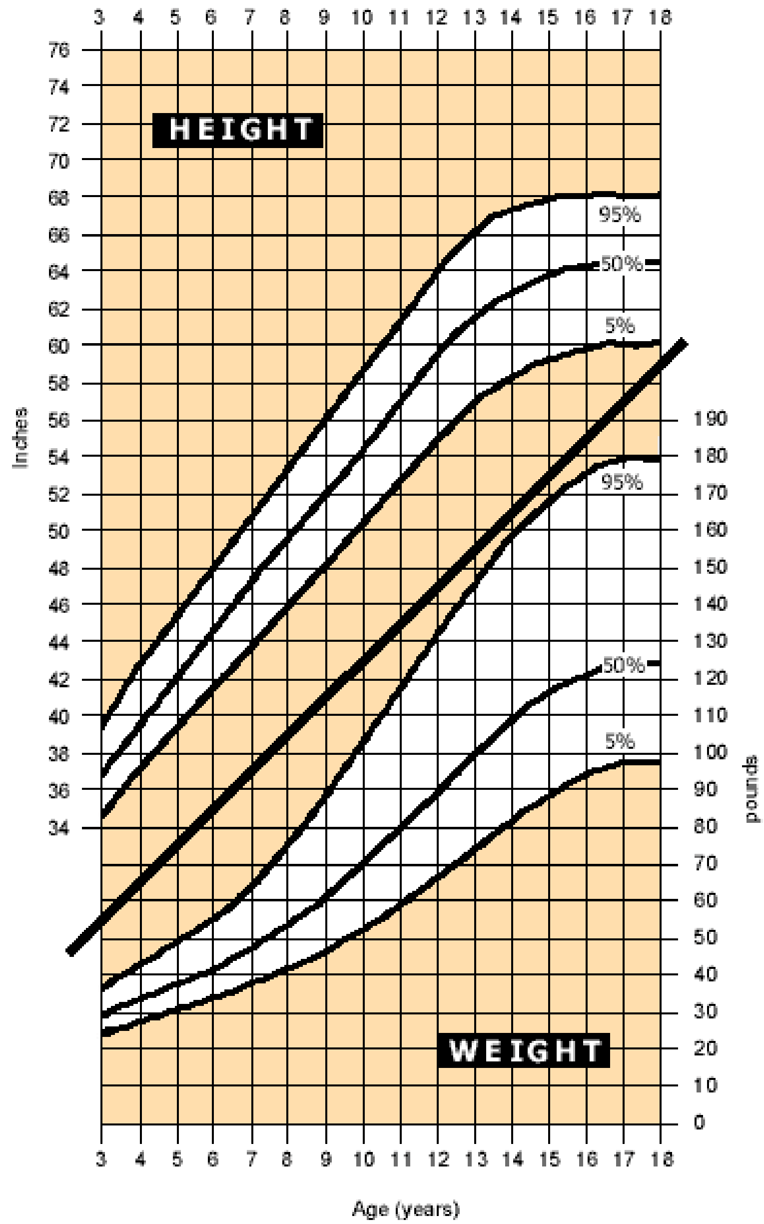


Figure 1(d): Growth chart for boys 3 to 18 years.
(Source: http://www.ama-assn.org/insight/h_focus/nemours/baby/grow.htm)

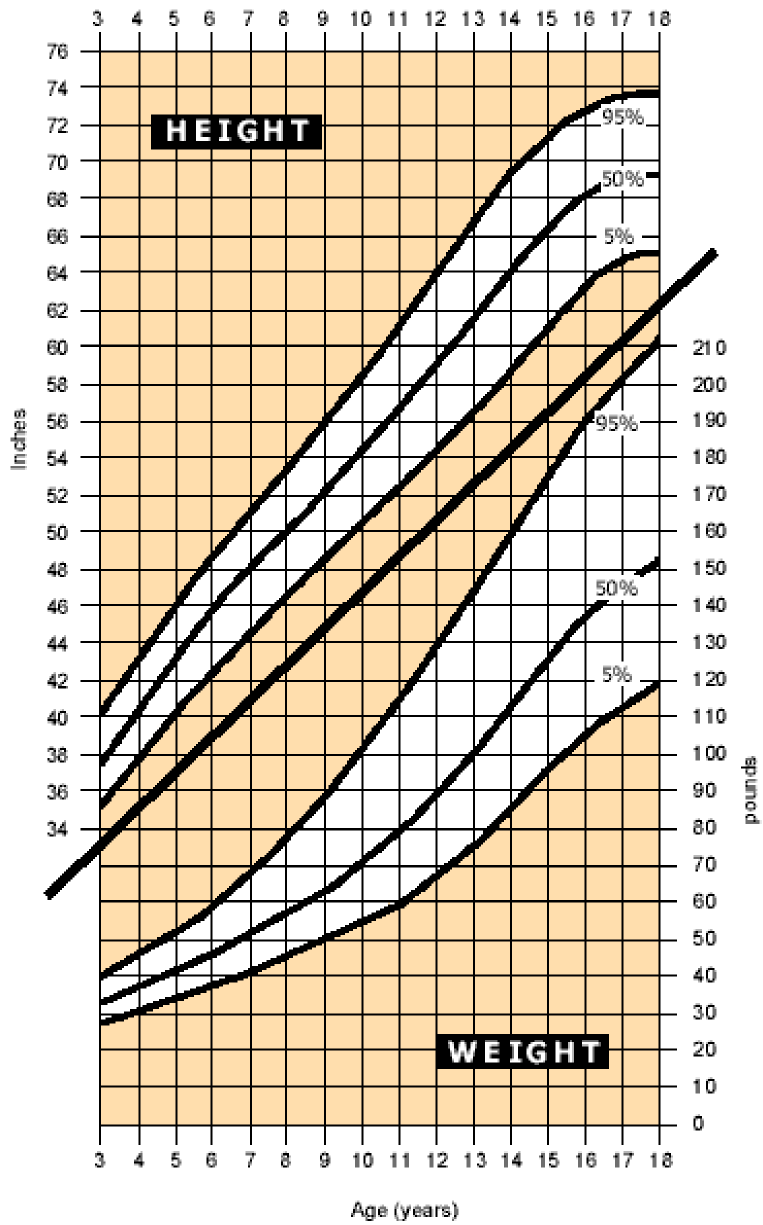


Figure 2: Changes in body proportions with age from 2 months to 25 yrs (Nelson et al., 1998).

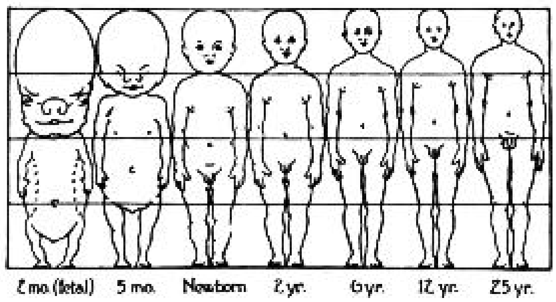
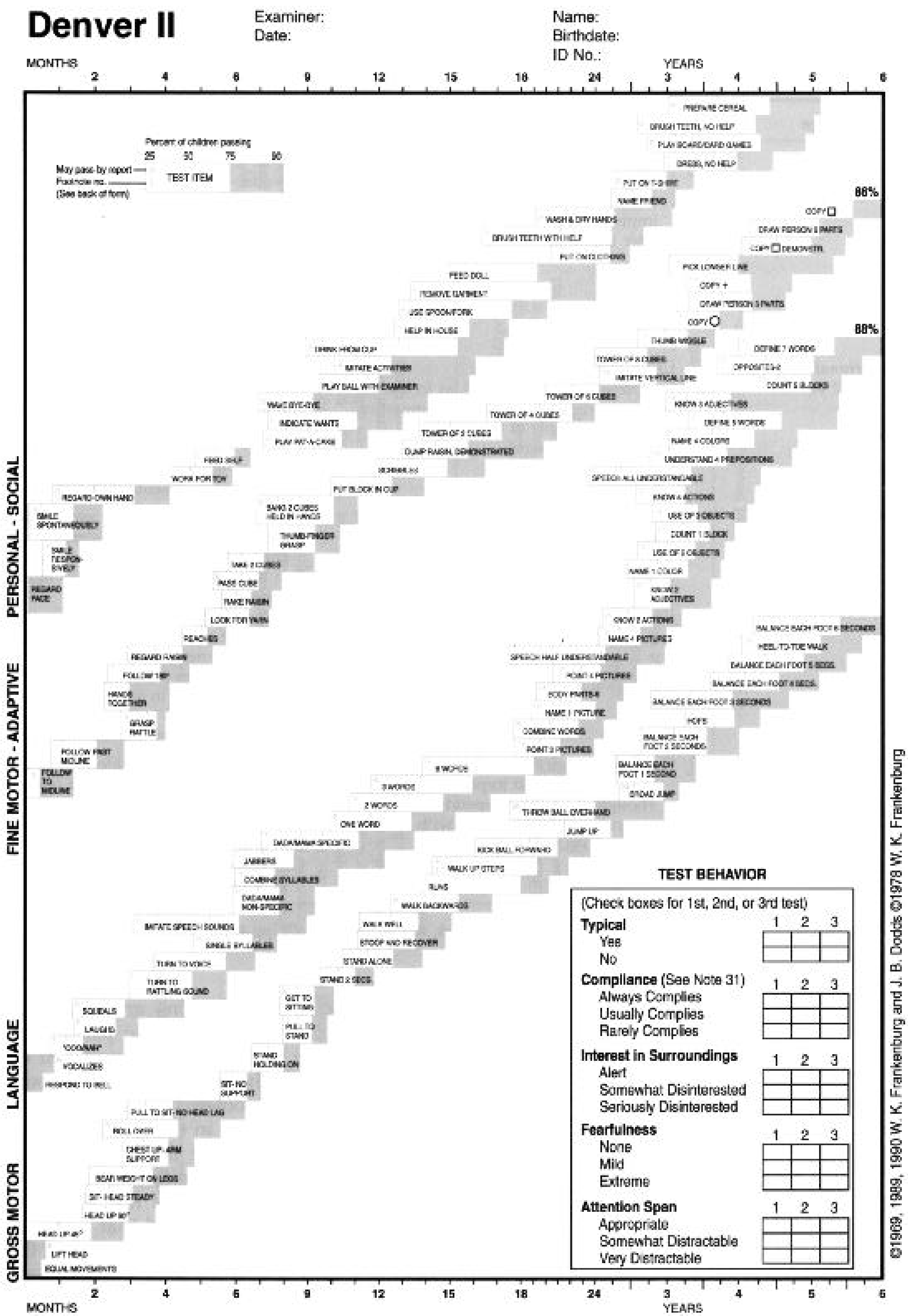


Figure 3: Developmental milestones as a function of age (Nelson et al., 1998).



Different developmental stages, milestones, and activities may have different significance for physicians and exposure/risk assessors. For example, developmental milestones such as talking and reading may be important to physicians but generally not to exposure/risk assessors. Conversely everyday behaviors such as drinking a lot of water or playing outside may be significant to exposure/risk assessors but not to physicians.

Many aspects of child development reflect continuous change, though 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 (e.g., at annual physical exams) and the growth rate is not constant (e.g., growth spurts).

The developmental phase(s) or time periods that are relevant to a risk assessment depend on the type of assessment. For lifetime cancer risks, childhood exposure is simply one component of the entire lifetime. In contrast, when assessing acute hazards, exposure/risk assessors may be most interested in the peak exposure for a young child over the course of an hour or less. For some non-cancer health effects, the relevant exposure duration could be a day, a week, a year, etc. For toxic effects that only occur if the child is exposed during a certain period of development (e.g., during the formation of the limbs *in utero*), only exposure during that developmental window may be significant.

Adults and children can react differently to the same exposure. For example, radiation treatment for cancer can permanently damage the child's developing central nervous system, which can inhibit normal growth (Bearer, 1995). For exposures such as this that may cause permanent or latent health impacts, analysts must develop approaches to characterize the impacts of health effects at different times on the developmental trajectories of children (McCormick, 1999).

Compared to adults, children have higher daily requirements for food, water, and oxygen per unit of body weight, and they have a higher ratio of surface area to volume. However, this does not necessarily mean that they are more vulnerable to health impacts than adults. In fact, their exposures and risks can be higher or lower than those experienced by adults (ILSI, 1992; Bearer, 1995; ILSI, 1996). This is because they have different exposures, pharmacokinetics, and pharmacodynamics than adults, and because the developmental changes during childhood can affect the metabolism, absorption, and excretion of substances and make children more or less vulnerable to health effects. Consequently, attention to toxicological information is critical when characterizing risks to children. (As noted earlier, pharmacokinetics/pharmacodynamics in children is not covered in this paper.)

2.2 Variability

Variability is a key challenge for children's exposure assessment. Children of the same age can exhibit tremendous variability. This 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 an mismatches that arise in the consideration 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. Since this type of data is not available, exposure/risk assessors typically use multiple data sources when assessing aggregate exposure and cumulative risk. Because these data often have a wide array of age categories, they often do not allow direct modeling of the aggregate exposures for children. An important challenge for analysts is to model the child of interest as he/she develops, rather than piecing together data to create "hypothetical" children that could not really exist (e.g., children that 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.

2.3 Representativeness

Another challenge when assessing children's exposure is the extent to which the available exposure data represent the population of interest (Thompson, 1999). 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:

- In the past decade, many fruits and vegetables that were available only seasonally now are available virtually year round.
- Many people consume an ever-increasing percentage of food away from home.
- Diets for children, which have historically included a large amount of fresh produce and tapwater, are shifting to include larger amounts of processed food, bottled water, and soft drinks.

3. Exposure Equations

Hubal et al. (2000) reviewed the factors that influence children’s exposure, and discussed the data available to characterize these factors. They defined three 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.

Hubal et al. (2000) provided several equations for estimating exposure. (These are discussed as Equations 1, 2, 3, 4, and 6, below. Equations 5 and 7 were not developed by Hubal et al. but they have been added because they reflect typical exposure relationships used by analysts.)

Equation 1: Inhalation Exposure

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

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

where

IR_{ma} = the child's respiration rate representing his activity level for that macroactivity (m^3/hr)
$T_{me/ma}$ = the time spent in that me/ma during the 24 hour period (hr/day)
C_{ame} = the air concentration measured in the microenvironment (mg/m^3)

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

Dermal exposure can be estimated individually for each microenvironment and macroactivity by using empirically derived transfer coefficients to aggregate the mass transfer associated with a series of contacts with a contaminated medium (Hubal et al., 2000. Dermal exposure averaged over a day for a single microenvironment/macroactivity ($E_{dme/ma}$) (in mg/day) is defined as:

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

where

DTC_{der} = dermal transfer coefficient for the me/ma (cm^2/hr)
$T_{me/ma}$ = the time spent in that me/ma during the 24 hour period (hr/day)
C_{surf} = total contaminant loading on 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 (Hubal et al., 2000). Dermal exposure averaged over a day for each microactivity ($E_{der/mi}$) (in mg/day) can be defined as:

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

where

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

For contaminants contacted in soil, exposure assessors may estimate the contaminant concentration on the surface (mg/cm^2) (C_{surf}) by using information about the dermal soil loading on the surface (mg/cm^2) (DSL) and a concentration of the contaminant in the soil (mg contaminant/mg soil).

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

Hubal et al. (2000) 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:

$$E_{diet} = W_T \bullet C_{food} + \Sigma_i \, [TE_{S/F} \bullet SA_{S/F} \bullet EF_{S/F} \bullet C_{surf}] + \Sigma_j \, [TE_{H/F} \bullet SA_{H/F} \bullet EF_{H/F} \bullet C_{hand}] \quad (4)$$

where

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

Converting this exposure to units of mg/d requires multiplying by the number of food items consumed per day (N) (in food items/day).

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 (not from Hubal et al., 2000) in which dietary ingestion exposure averaged over a day (E_{ing}) (in mg/day) is defined as:

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

where

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

Equation 6: Non-Dietary Ingestion

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

$$E_{nding/mi} = TE_{xm} \bullet SA_x \bullet EF \bullet C_x \quad (6)$$

where

x	=	object that is mouthed (including hand)
TE_{xm}	=	transfer efficiency, fraction transferred from object or hand to mouth (unitless)
SA_x	=	area of object or hand that is mouthed (cm^2/event)
EF	=	frequency of mouthing event over a 24-hour period (events/day)
C_x	=	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 to the contaminants from the various microenvironments 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 (e.g., a year or a lifetime). For this reason, it is very important for exposure/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 zero (on days when no grapes are consumed) and non-zero on another day (when grapes are consumed). Over the longer term, the average grape consumption will be greater than zero, but less than highest daily consumption amount. Thus, over time, there will be regression to the mean. This phenomenon must be properly accounted for in exposure/risk assessment, but it is challenging because currently very few longitudinal data exist.

Equation 7: Estimation of Potential Dose

To estimate a potential dose (mg/kg/d) for risk assessment the results of the equations above may need to be divided by body weight of the exposed individual (BW) or some function of body weight:

$$\text{Dose} = E/BW \qquad (7)$$

where

E	=	exposure (mg/d)
BW	=	body weight (kg)

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

Discussion of Anatomical and Behavioral Exposure Factors

Sections 4 through 8 of this paper discuss the various anatomical and behavioral exposure factors utilized in Equations 1 through 7. For each exposure factors, 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 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. Note that EPA's Child-Specific Exposure Factors Handbook (CSEFH) was the source for nearly all the data sources listed in this paper. Each source is given "source number" in the left-hand column of the table for identification purposes. For example, in Table 1, the first source, NHANES III, is given the source number "BW(1)."
- Lists the age categories used by each source and, when available, the number of subjects in each age group.
- Provides a general assessment of (1) the data quality based on the criteria and judgments given in the EPA's Child-Specific Exposure Factors Handbook, and (2) the extent of generalization (as judged by the issue paper author).

Following each table, a figure is provided for each exposure factor that graphically displays the ages of the children for which data were collected by each source. Each figure is divided into three age ranges:

- Figure (a) shows birth to 1 month (by days).
- Figure (b) shows birth to 3 years (by month).
- Figure (c) shows birth to 21 years (by year).

For each of these three age ranges, the figure provides information on the ages of children studied by each source listed in the preceding table. Data are displayed as follows:

- The figures identify the studies using the source number provided in the left column of the table. The reader should refer to the table for the specific source reference.
- An "x" under a specific age in the figure indicates that the study in question did report measurements for children at that age.
- A bar is used between endpoints of a range to indicate that the study reported measurements for children within that age range. Note when an age range is given, the available data generally include data for the entire month or year given as the end of the age range. This fact is reflected in the figures. For example, for body weight, one of the sources provides data for the age range 7- 12 months. This range is shown on the corresponding figure as a bar extending from 7 months to just before 13 months to indicate that the data cover the full duration of twelfth month.

All figures (a-c) are shown for each factor, even when no data are available for a particular age range. Section 9 of this paper synthesizes these figures to show the availability of data for all of the factors and to reveal where additional information may be needed. Note that the age categories used in the figures were selected as a convenient means of summarizing the available data and were not intended as recommendations of appropriate age categories.

4. Anatomical changes during growth

4.1 Body weight (BW)

Body weight is critical to appropriately assessing dose (see Equation 7). Data from large cohorts can be used to develop complete growth charts and to characterize the variability in body weight around each age (see Figures 1a-1d for an example). Any age grouping is possible since these data are continuous and they may be converted into discrete age bins. Table 1 summarizes the age groupings provided by the data sources listed in EPA's Child-Specific Exposure Factors Handbook. Figures 4a-c display these data by age categories.

The most extensive studies of body weights for children come from the National Center for Health Statistics (NCHS) National Health and Nutrition Examination Survey (NHANES) II and III:

- NHANES II provided body weight data for children between 6 months and 19 years at each age. Burmaster et al. (1997) reanalyzed NHANES II data and found that body weight data distribute lognormally. (The fact that these data have been reanalyzed suggests that they are likely to be accessible.)
- The data from NHANES III were recently released and provide body weight data for children and young adults between 2 months and 24 years of age. They are represented in Table 1. These data are also publicly available. Since NHANES III data are reported for each year of age between 1 and 17 years, combining the results into different age ranges and quantifying variability among children of the same age should be feasible.

The NHANES II and NHANES III could be compared to determine whether there are significant differences that might indicate a time trend. For example, are children larger now than children in the past? 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 might lead to greater variance in the weights of infants and children.

Remarkably, weight change of an individual child as a function of age and the correlation of body weight with other exposure factors are less well studied. For example, do children born at the 90^{th} weight percentile stay at the 90^{th} 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 body weight. Few longitudinal data exist concerning body weight as a function of age. This type of data may not be very significant when analyzing chronic effects for an average child (e.g., the median or mean). However, if the analysis focuses on a low percentile individual child (e.g., a 5^{th} percentile child), then it may be important to factor in the tendency of regression to the mean and to be cautious in constructing a 5^{th}

percentile time weighted average estimate of body weight by using weights observed for 5th percentile individuals at different ages.

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

Exposure Variable (Source number)	Description	Data Sources	Age groups used for reporting data	Quality and extent of generalization
BW (1)	Body weight	NHANES III, 2000 (NCHS as reported in CSEFH)	2 mo. (n=243) 3 mo. (n=190) 2-6 mo. (n=1020) 7-12 mo. (n=1072) 1 yr. (n=1258) 2 yr. (n=1513) 3 yr. (n=1309) 4 yr. (n=1284) 5 yr. (n=1234) 6 yr. (n=750) 7 yr. (n=736) 8 yr. (n=711) 9 yr. (n=770) 10 yr. (n=751) 11 yr. (n=754) 12 yr. (n=431) 13 yr. (n=428) 14 yr. (n=415) 15 yr. (n=378) 16 yr. (n=427) 17 yr. (n=410) 18-24 yr. (n=2532)	Quality = High Extent of generalization = High
BW(2)	Body weight	Hamill et al., 1979 (NCHS as reported in CSEFH)	(n=867) 0 mo. 1 mo. 3 mo. 6 mo. 9 mo. 12 mo. 18 mo. 24 mo. 30 mo. 36 mo	

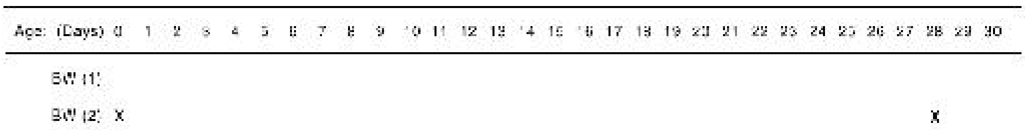


Figure 4a Summary of Available Body Weight (BW) Data by Days

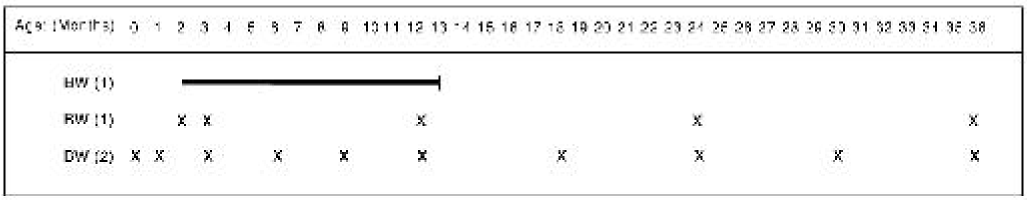


Figure 4b Summary of Available Body Weight (BW) Data by Months

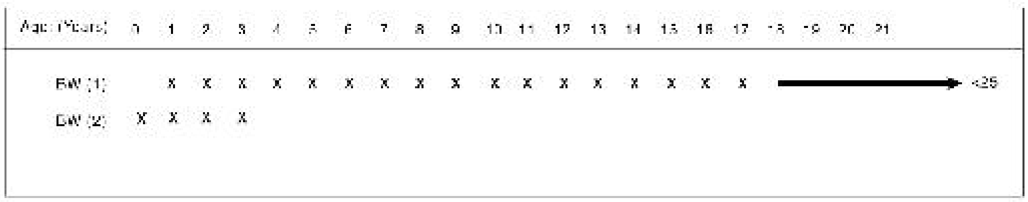


Figure 4c Summary of Available Body Weight (BW) Data by Years

X = Reported at specific age

|—| = Reported within age range

4.2 Skin surface area (SA and SA/BW)

Skin surface area information is most often used in dermal assessments. (Dermal assessments also incorporate a number of behavioral factors, which are discussed in Section 7.) Direct surface area measurements are much less common than body weight measurements. For example, body weight and height (which correlate with skin surface area) are frequently measured by physicians, but body surface area is rarely measured.

Instead, skin surface area is generally calculated from body weight and using relationships based on data collected 65 years ago by Boyd (1935). Table 2 summarizes the age groupings for surface area provided by the data sources listed in EPA's Child-Specific Exposure Factors Handbook. Figures 5a-c display these data by age categories. Note that insufficient data exist for children under age 2 years. For very small infants (e.g., low birth weight infants), extrapolations must be performed to estimate surface area because Boyd's relationship for estimating surface area from height and weight data did not include these children.

Many of the ideas discussed in Section 4.1 for the body weight factor apply to surface area as well. Assuming that the NHANES III data are available, the estimates for SA could be updated to reflect these new data. Since surface area correlates with body weight, the uncertainties about body weight estimates also affect surface area estimates.

For most assessments of dermal exposure, analysts consider the extent to which different parts of the child’s body might be exposed. Although reasonably reliable estimates for total surface area for children over 2 years old are available, estimates of surface area associated with specific parts of the body are less available and less reliable. This can be important when combined with information about children’s behavior. For example, consider a child wearing shorts who sits in sand to play, or a child who is crawling and pulls his or her legs and hands over the floor. The fact that children do these behaviors at different ages (and sizes) may impact estimates of exposure.

Table 2: Surface Area Data Sources and Age Categories Used

Exposure Variable (Source number)	Description	Data Sources	Age groups used for reporting data	Quality and extent of generalization
SA (1)	Surface area	EPA, 1985, Using data from NHANES II – separately reported percentiles for both boys and girls (from CSEFH)	2-3 yr. (n=?) 3-4 yr. 4-5 yr. 5-6 yr. 6-7 yr. 7-8 yr. 8-9 yr. 9-10 yr. 10-11 yr. 11-12 yr. 12-13 yr. 13-14 yr. 14-15 yr. 15-16 yr. 16-17 yr. 17-18 yr.	Quality = High Extent of generalization = Medium (based on extrapolation using relatively old data, inadequate information for children under age 2)
SA/BW (1)	Surface area/ body weight ratio	Phillips et al., 1993 (reported in CSEFH)	0-2 yrs. 2.1-17.9 yrs.	

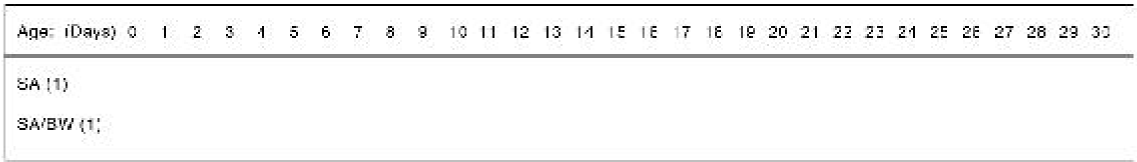


Figure 5a Summary of Available Surface Area (SA) Data by Days

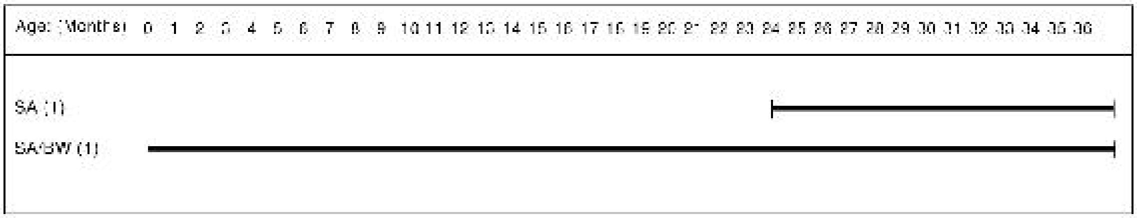


Figure 5b Summary of Available Surface Area (SA) Data by Months

Figure 5c Summary of Available Surface Area (SA) Data by Years

= Reported within age range

5. 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 U.S. Department of Agriculture (USDA) Nationwide Food Consumption Survey (NFCS) and Continuing Survey of Food Intakes by Individuals (CSFII) 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 data makes the assessment of lifetime aggregate exposure challenging, particularly with respect to understanding important sources of correlation. For example: Do children that eat a relatively large amount of grapes as 9-month olds continue to consume a lot of grapes into their teens, or is eating a lot of grapes more characteristic of a phase or of 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 5 reviews six key exposure factors concerning ingestion in children:

- Section 5.1 reviews the age categories used in the one major survey that assesses ***food intake*** amounts.
  - Section 5.2 covers ***drinking water ingestion***, for which data are available from several large studies.
  - Sections 5.3 and 5.4 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 non-dietary 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. While the data may be accessible by contacting the researchers that 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 5.5 and 5.6 review the age category information for ***soil ingestion*** and ***for mouthing non-dietary objects***, respectively.

5.1 Food intake (IR_{food}/BW)

Table 3 summarizes the age groupings for food intake provided by the U.S. Department of Agriculture's Continuing Survey of Food Intakes by Individuals (CSFII) study—the data source listed in EPA's Child-Specific Exposure Factors Handbook. Figures 6a-c display these data by age categories. The USDA's CSFII study provides data from a national survey of food consumption. The results include data for total fruits, total vegetables, total grains, total meats, total fish, total dairy products, and total fats. USDA collects these national data using a stratified sampling strategy that specifically collects food consumption information from children. The data are reported as intake rates per unit of body weight (g of food/kg of body weight/d) (i.e., data were collected for each individual so the reported data preserve the correlation between food consumption and body weight). Thus, no additional calculation is needed to account for body weight when estimating dose. The food intake factor comes from Equation 5 and it relates to the W_T factor mentioned by Hubal et al. (2000) 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 body weight [BW]).

Unfortunately the USDA data do not provide information over long time periods, or longitudinal data for individual children. For a "typical child," there are some long-term dietary constraints that must apply (e.g., requirements for caloric intake, sufficient vitamins and minerals). However, the extent to which individual children meet these requirements is unknown. Correlation of diet with socioeconomic factors may also be an important issue in the context of the exposure assessment.

Table 3: Food Intake Data Sources and Age Categories Used

Exposure Variable (Source number)	Description	Data Sources	Age groups used for reporting data	Quality and extent of generalization
Food Ingestion (IR_{food}/BW) (1)	Food intake (for various foods)	EPA, 2000. (Data from USDA CSFII) (Reported in the CSEFH)	<1 yr. (n=359) 1-2 yr. (n=1356) 3-5 yr. (n=1435) 6-11 yr. (n=1432) 12-19 yr. (n=1398)	Quality=High in average, low in long-term, upper percentiles Extent of generalization = Medium (Lack of long-term focus)

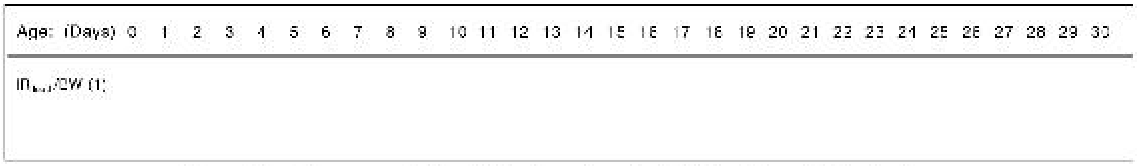


Figure 6a Summary of Available Ingestion Rate (IR) of Food Data by Days

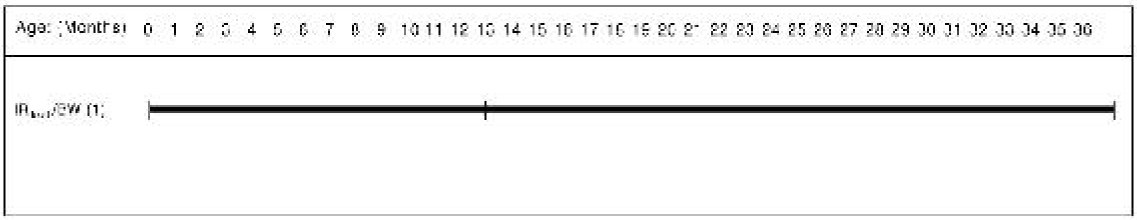


Figure 6b Summary of Available Ingestion Rate (IR) of Food Data by Months

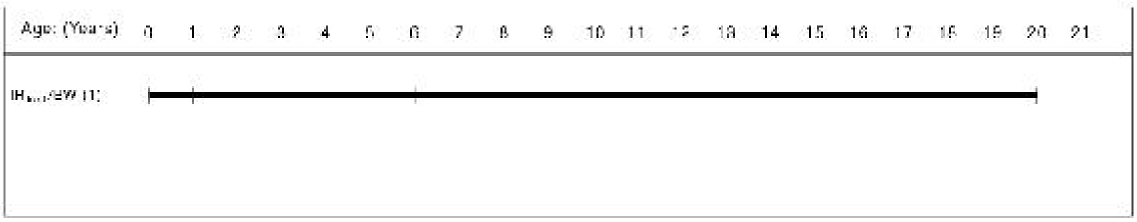


Figure 6c Summary of Available Ingestion Rate (IR) of Food Data by Years

= Reported within age range

5.2 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. Table 4 summarizes the age groupings for drinking water consumption provided by the data sources listed in EPA's Child-Specific Exposure Factors Handbook. Figures 7a-c display these data by age categories.

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 (e.g., people might 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 have been analyzed to characterize the variability in the population. The data appear to distribute lognormally (Roseberry and Burmaster, 1992).

Table 4: Drinking Water Data Sources and Age Categories Used

Exposure Variable (Source number)	Description	Data Sources	Age groups used for reporting data	Quality and extent of generalization
IR_{water} and IR_{water}/BW (1)	Drinking water intake for total fluid intake	EPA, 2000 (Using data from USDA's CSFII) and Ershow and Cantor, 1989 (Reported in CSEFH)	0<1 yr. (n=359) 1-10 yr. (n=3980) 11-19 yr. (n=1641)	Quality=High Extent of generalization = High
IR_{water} and IR_{water}/BW (1)	Drinking water intake for total fluid intake	EPA, 2000 (Using data from USDA's CSFII) and Ershow and Cantor, 1989 (Reported in CSEFH)	<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)	

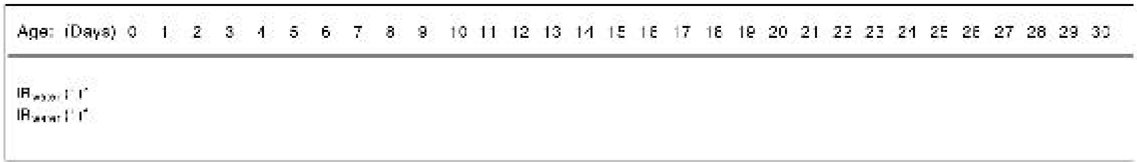


Figure 7a Summary of Available Ingestion Rate (IR) of Water Data by Days

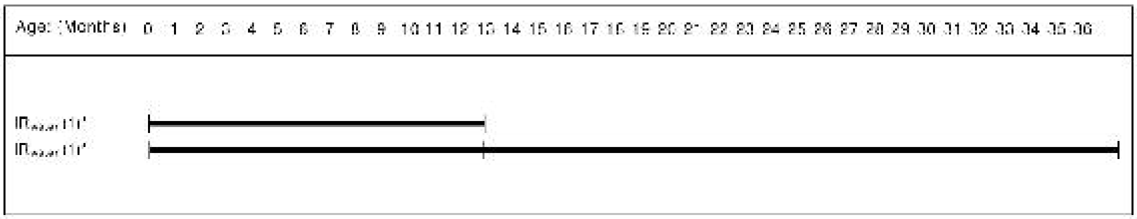


Figure 7b Summary of Available Ingestion Rate (IR) of Water Data by Months

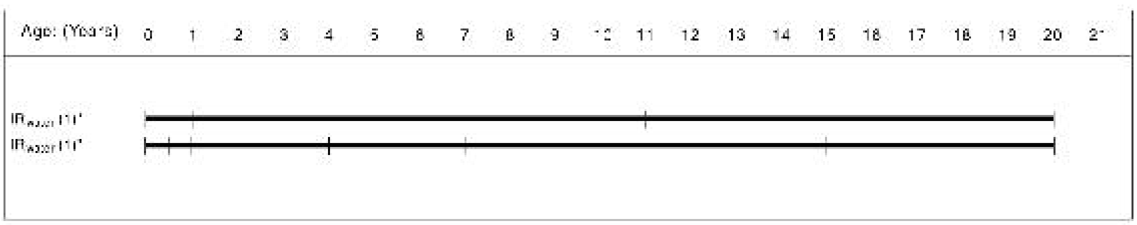


Figure 7c Summary of Available Ingestion Rate (IR) of Water Data by Year

*Reported for IR_{water} and IR_{water}/BW

|—| = Reported within age range

5.3 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. Figures 8a-c display these data by age categories. These studies included estimates of infants up until age 1. Most of the studies have focused on quantifying milk ingestion for young infants (under 6 months). Note that no data are available for children that are breast-fed beyond age 1.

Information about the percentages of infants that are breast-fed is relatively sparse. One study (NAS, 1991) provides data for the percentage of newborns being breast-fed and of 5- to 6-month-old infants being breast-fed. To estimate a population risk (or population exposure) for this exposure pathway, additional information about the decline in the percentage of infants that are breast-fed may be needed. In general, these data are relatively sparse and they may not reflect current trends for breast-feeding. Shorter postpartum hospitalization for normal deliveries and longer infant hospitalization for very premature infants may impact the amount of breast milk consumed and the tendency to breast-feed.

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

Exposure Variable (Source number)	Description	Data Sources	Age groups used for reporting data	Quality and extent of generalization
$IR_{breastmilk}$ (1)	Breast milk intake	Pao et al., 1980 (Reported in CSEFH)	Completely breast-fed 1 mo. (n=11) 3 mo. (n=2) 6 mo. (n=1) Partially Breastfed 1 mo. (n=4) 3 mo. (n=11) 6 mo. (n=6) 9 mo. (n=3)	Quality=Medium Extent of generalization = Low (based on small sample size and inability to characterize variability)
$IR_{breastmilk}$ (2)	Breast milk intake	Dewey and Lonnerdal, 1983 (Reported in CSEFH)	1 mo. (n=16) 2 mo. (n=19) 3 mo. (n=16) 4 mo. (n=13) 5 mo. (n=11) 6 mo. (n=11)	
$IR_{breastmilk}$ (3)	Breast milk intake	Butte et al, 1984 (Reported in CSEFH)	1 mo. (n=37) 2 mo. (n=40) 3 mo. (n=37) 4 mo. (n=41)	
$IR_{breastmilk}$ (4)	Breast milk intake	Neville et al., 1988 (Reported in CSEFH)	Intake per day Each day for days 1 to 11 (n=7 to 12) For days 14, 21, 28, 35, 42, 49, 56 (n=10 to 13) For days 90, 120, 150, … 360 (n=9 to 13)	
$IR_{breastmilk}$ (5)	Breast milk intake	Dewey et al., 1991a,b (DARLING Study) (Reported in CSEFH)	3 mo. (n=73) 6 mo. (n=60) 9 mo. (n=50) 12 mo. (n=42)	

Age: (Days)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Reference (1)																													x		
Reference (2)																													x		
Reference (3)																													x		
Reference (4)		x	x	x	x	x	x	x	x	x	x	x			x							x							x		
Reference (5)																															

Figure 8a Summary of Available Ingestion Rate (IR) of Breast Milk Data by Days

Age: (Months)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Reference (1)		x		x			x			x																											
Reference (2)		x	x	x	x	x	x																														
Reference (3)		x	x	x	x																																
Reference (4)	x	x	x	x	x	x	x	x	x	x	x	x	x																								
Reference (5)				x			x			x			x																								

Figure 8b Summary of Available Ingestion Rate (IR) of Breast Milk Data by Months

Age: (Years)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Reference (1)																						
Reference (2)																						
Reference (3)																						
Reference (4)																						
Reference (5)																						

Figure 8c Summary of Available Ingestion Rate (IR) of Breast Milk Data by Years

X = Reported at specific age

5.4 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 reported in the studies covered by EPA's Child-Specific Exposure Factors Handbook. Figures 9a-c display these data by age categories. These studies included estimates of infants up until age 1.

While general intake data are available from USDA's large CSFII database, most of the fish consumption data come from relatively small studies. These data are difficult to extrapolate to the larger population and make 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. For example, Ruffle et al. (1994) fit lognormal distributions to the daily fish consumption rates obtained in the Tuna Research Institute Survey.

Table 6: Fish Intake Data Sources and Age Categories Used

Exposure Variable (Source number)	Description	Data Sources	Age groups used for reporting data	Quality and extent of generalization
IR_{fish} and IR_{fish}/BW (1)	General intake rates (freshwater and estuarine, marine, and total)	EPA, 1996 (Data from USDA CSFII) (Reported in the CSEFH)	14 or under (n>1000) 15-44 yr. (n>1000)	Quality=High in average, low in long-term upper percentiles Extent of generalization = Medium (Some data relatively old)
IR_{fish} (2)	General intake rates of fish consumers	Javitz, 1980 analysis of the Tuna Research Institute Survey (Reported in the CSEFH)	0-9 yr. 10-19 yr.	
IR_{fish} (3)	General intake rates of fish consumers (freshwater finfish, saltwater finfish, and shellfish)	Rupp et al., 1980 of the Tuna Research Institute Survey (Reported in the CSEFH)	<11 yr. 12-18 yr. 19+ yr.	
IR_{fish} and IR_{fish}/BW and $N_{fish\ meals}$ (4)	Fish meals per month for anglers with fishing licenses	West et al., 1989 (Reported in CSEFH)	1-5 yr. 6-10 yr. 1-20 yr.	
IR_{fish} (5)	Intake rate for Native American fishers	Columbia River Inter-Tribal Fish Commission (CRITFC), 1994 (Reported in CSEFH)	<5 yr. (n=204)	
$N_{fish\ meals}$ (6)	General number of fish eating events (meals)	Tsang and Klepeis, 1996 (Reported in CSEFH)	1-4 yr. 5-11 yr. 12-17 yr.	

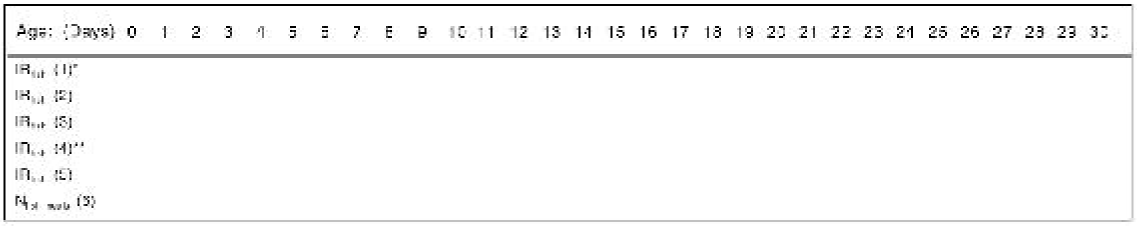


Figure 9a Summary of Available Ingestion Rate (IR) of Fish Consumption Data by Days

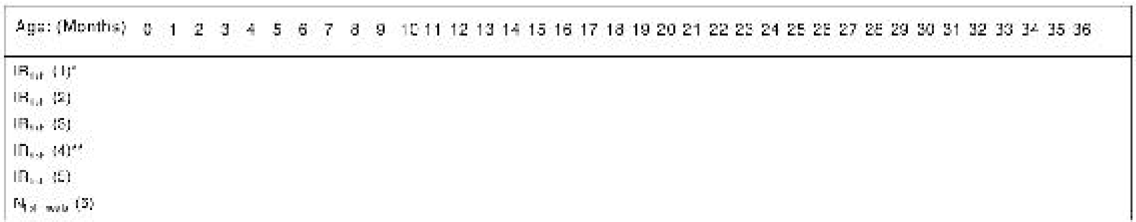


Figure 9b Summary of Available Ingestion Rate (IR) of Fish Consumption Data by Months

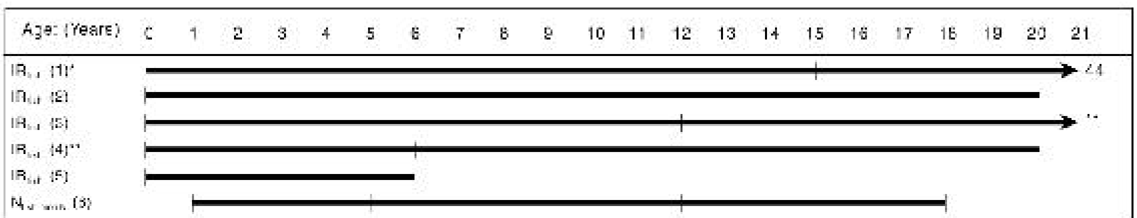


Figure 9c Summary of Available Ingestion Rate (IR) of Fish Consumption Data by Years

* Reported for IR_{fish} and IR_{fish}/BW
** Reported for IR_{fish}, IR_{fish}/BW, and $N_{fish\ meals}$
*** Upper age limit not specified

= Reported within age range

5.5 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 (using duplicate meals).
- Very limited exposure data are available for intentional ingestion of soil, known as pica.

Table 7 summarizes the age groupings for soil ingestion data from the studies covered by EPA's CSEFH. Figures 10a-c display these data by age categories**.** The methodology used to estimate soil ingestion is indirect, relatively complicated, and prone to errors. In addition, the studies reflect short-term, small local analyses that do not extrapolate easily to national, long-term studies.

In general, soil ingestion tendencies probably vary considerably over days and characterization of this variability is relatively limited. A significant amount of uncertainty exists about the amount of soil ingested by children. In addition, the extent to which children ingest the soil as a function of different microactivities is unknown. As discussed by Hubal et al. (2000) and shown in Equation 4, one 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 between 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. More data for very young children is needed. In addition, data for children over age 7 years are also missing. While this behavior is likely to be reduced significantly by age 7 years, some soil ingestion may continue beyond that age associated with outdoor play, etc.

Table 7: Soil Ingestion Data Sources and Age Categories Used

Exposure Variable (Source number)	Description	Data Sources	Age groups used for reporting data	Quality and extent of generalization
IR_{soil} (1)	Soil intake – non-intentional	Binder et al., 1986 (Reported in CSEFH)	1-3 yr. (n=65)	Quality=Medium for average, long-term central estimates) Extent of generalization = Low (All non-national data, short-term studies, not all ages of children included)
IR_{soil} (2)	Soil intake – non-intentional	Clausing et al., 1987 (Reported in CSEFH)	2-4 yr. (n=18)	
IR_{soil} (3)	Soil intake – non-intentional	Calabrese et al., 1989 (Reported in CSEFH)	1-4 yr. (n=64)	
IR_{soil} (4)	Soil intake – non-intentional	Davis et al., 1990 (Reported in CSEFH)	2-7 yr. (n=104)	
IR_{soil} (5)	Soil intake – non-intentional	Van Wijnen et al., 1990 (Reported in CSEFH)	1-5 yr. (n=292)	
IR_{soil} (6)	Soil intake (pica)	Calabrese et al., 1991 (Reported in CSEFH)	3.5 yr. (n=1)	

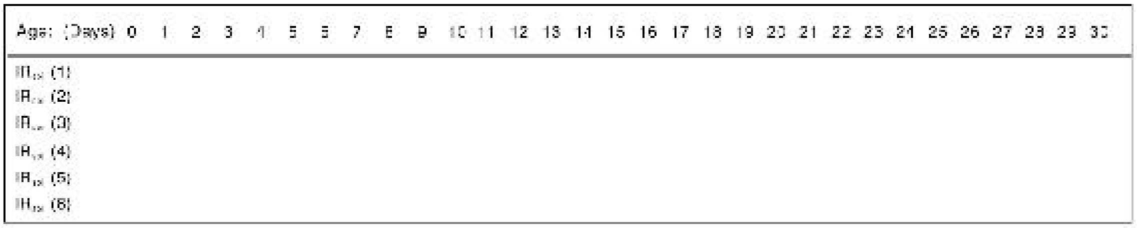


Figure 10a Summary of Available Ingestion Rate (IR) of Soil Ingestion Data by Days

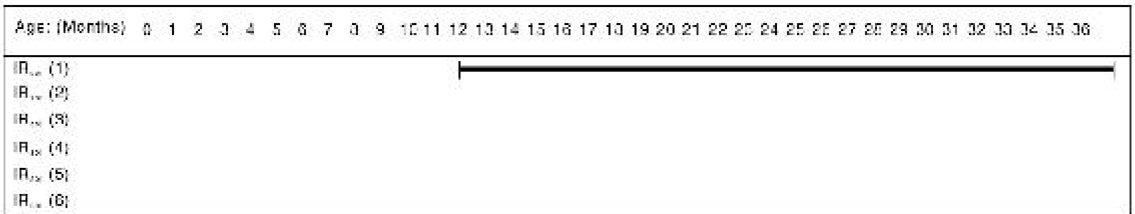


Figure 10b Summary of Available Ingestion Rate (IR) of Soil Ingestion Data by Months

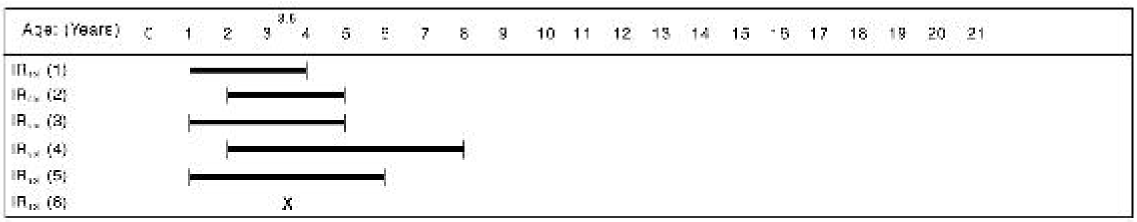


Figure 10c Summary of Available Ingestion Rate (IR) of Soil Ingestion Data by Years

X = Reported at specific age

|—| = Reported within age range

5.6 Other non-dietary ingestion

Children may be exposed to environmental pollutants when they place non-food 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). While these are related concepts, they are not the same, and slightly different equations are needed to estimate exposure based on these different data.

Table 8 summarizes the age groupings for non-dietary ingestion data from the studies included in EPA's CSEFH. Figures 11a-c display these data by age categories. In general the link between duration of mouthing and microactivities or macroactivities is relatively unexplored. The studies included here represent very small non-national studies that are typically of a short-duration. The mouthing duration data collected by Juberg et al. (2000) suggests 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. While 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, cigarettes, etc.

Table 8: Non-dietary Ingestion Data Sources and Age Categories Used

Exposure Variable (Source number)	Description	Data Sources	Age groups used for reporting data	Quality and extent of generalization
T_{mouth} (1)	Duration of mouthing	Groot et al., 1998 (Reported in CSEFH)	3-6 mo. (n=5) 6-12 mo. (n=14) 12-18 mo. (n=12) 18-36 mo. (n=11)	Quality= *? (Not in CSEFH)* Extent of generalization = Medium for average for young children, low for long-term central estimates and for all extremes
T_{mouth} (2)	Duration of mouthing	EPA analysis of Davis et al., 1995 (Reported in CSEFH)	10-60 mo. (n=92)	
T_{mouth} (3)	Duration of mouthing	Juberg et al., 2000	0-18 mo. (n=275) 19-36 mo. (n=110)	
EF (1)	Frequency of mouth contact	Reed et al., 1999 (Reported in CSEFH)	2-6 yr. (n=30)	
EF (2)	Frequency of mouth contact	Zartarian et al., 1997 (Reported in CSEFH)	2.5-4.2 yr. (n=4)	

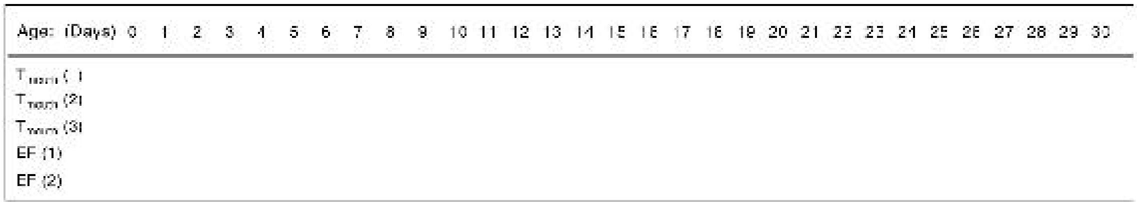


Figure 11a Summary of Available Other Non-Dietary Ingestion Data by Days

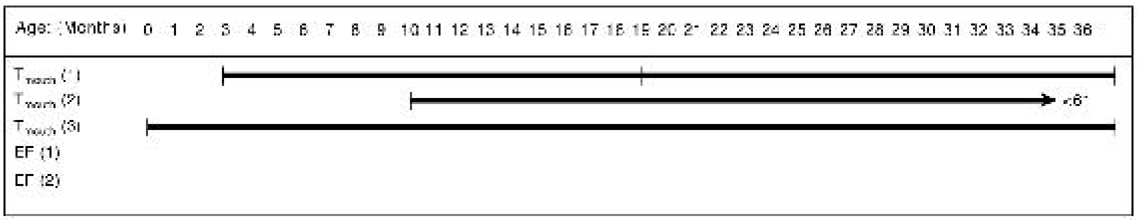


Figure 11b Summary of Available Other Non-Dietary Ingestion Data by Days

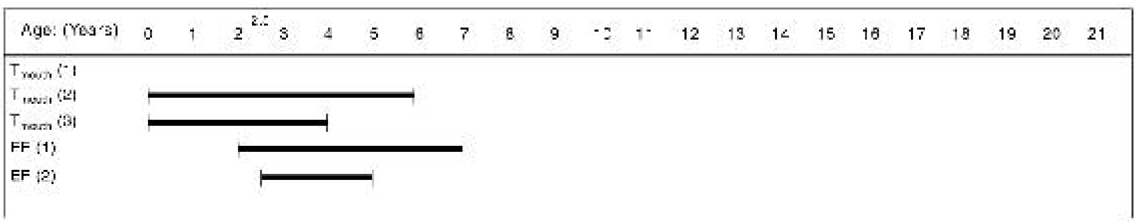


Figure 11c Summary of Available Other Non-Dietary Ingestion Data by Days

= Reported within age range

6. Inhalation (IR_{ma})

A number of studies provide data on inhalation rates for children. Inhalation rates vary as a function of activity (i.e., 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 inhalation data from the studies covered by EPA's handbook. Figures 12a-c display these data by age categories.

The estimates by Layton et al. (1993) rely on estimating inhalation rates based on food energy intake and on basal metabolic rate. Since dietary data are available for large numbers of people, the sample sizes possible with this approach can be very large. However, since 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. The fact that Layton et al. (1993) found similar estimates of inhalation rates using different data and different modeling approaches is reassuring. Nonetheless, some uncertainties remain about the results. In addition, different age categories were used in the different approaches due to differences in the age categories used 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 body weight or address their correlation. Studies with longitudinal data on inhalation rates are missing and additional studies are needed to better characterize inhalation rates of children as a function of age and to estimate their average inhalation rates.

Table 9: Inhalation Rate Data Sources and Age Categories Used

Exposure Variable (Source number)	Description	Data Sources	Age groups used for reporting data	Quality and extent of generalization
IR_{ma} (1)	Inhalation rate of healthy and asthmatic youth	Linn et al., 1992 (Reported in CSEFH)	10-12 yrs. (n=17) 13-17 yrs. (n=19) 11-16 yrs. (n=13)	Quality= Medium Extent of generalization = Medium (Limited data for very young children, small sample sizes)
IR_{ma} (2)	Inhalation rate of healthy youth exposed to oxidant pollution	Spier et al. 1992 (Reported in CSEFH)	10-12 yrs. (n=17) 13-17 yrs. (n=19)	
IR_{ma} (3)	Inhalation rate for "young children" (3-5.9), "children" (6-13)	Adams, 1993 (Reported in CSEFH)	3-5.9 yr. 6-12.9 yr.	
IR_{ma} (4)	Inhalation rate estimated based on food energy intake	Layton, 1993 (Reported in CSEFH)	<1 yrs. 1-2 yrs. 3-5 yrs. 6-8 yrs. 9-11 yrs. 12-14 yrs. 15-18 yrs.	
IR_{ma} (5)	Inhalation rate estimated based on basal metabolic rate	Layton, 1993 (Reported in CSEFH)	0.5 -<3 yrs. 3-<10 yrs. 10-<18 yrs.	

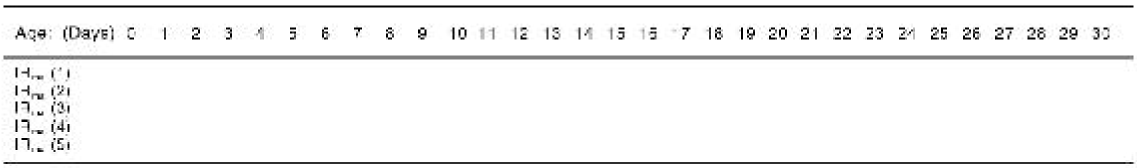


Figure 12a Summary of Available Inhalation Rate Data by Days

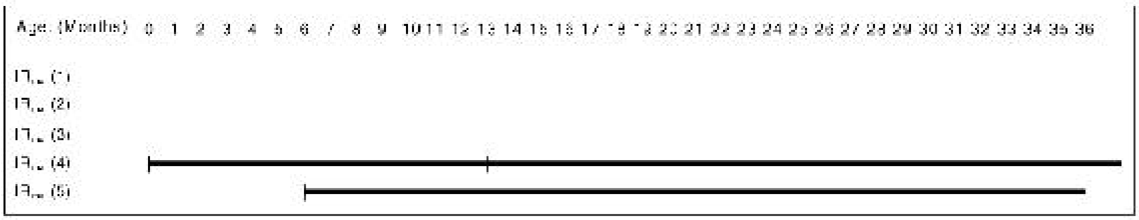


Figure 12b Summary of Available Inhalation Rate Data by Months

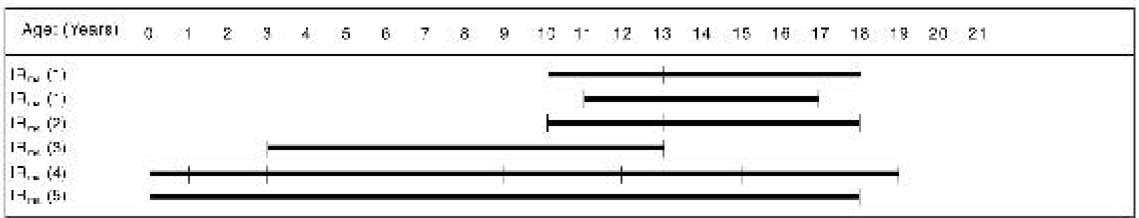


Figure 12c Summary of Available Inhalation Rate Data by Years

|—| = Reported within age range

7. 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. Most of the existing data focus on dermal exposure from contaminated soil. The EPA's CSEFH does not recommend using a single value for soil adherence. Instead the Agency recommends that analysts find the activity that is most similar to the one of interest and estimate the dermal soil loading based on this.

Table 10 summarizes the age groupings for inhalation data from the studies covered by EPA's CSEFH. Figures 13a-c display these data by age categories. Kissel et al. (1996a; 1996b) and Holmes et al. (1996) provided data for the rate of soil adherence to the skin as a function of different activities based on controlled experiments. The relatively small database leaves a high degree of uncertainty in 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 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 surface area of the body or part of the body may be necessary. The age categories for surface area data are provided in Section 4.2.

One factor that may impact 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 impact both the activities and the clothing worn, and data that account for this correlation are not currently available for children. Kissel et al. (1996) and Holmes et al. (1996) do note the types of clothing worn by participants and the month of the data collection. Reanalysis of the existing data might be possible by contacting the study authors, but it is probably of limited use given the very small sample sizes.

Given the limitations in the number of microenvironments and activities for which data are available, additional data are needed to better characterize dermal contact.

Table 10: Soil Adherence Data Sources and Age Categories Used

Exposure Variable (Source number)	Description	Data Sources	Age groups used for reporting data	Quality and extent of generalization
DSL (1)	Soil Adherence from 1.5 hours of indoor Tae Kwon Do	Kissel et al. (1996b), Holmes et al. (1996) (Reported in CSEFH)	8-42 yrs. (n=7)	Quality= Low Extent of generalization = Low (Data are very limited)
DSL (1)	Soil Adherence from 2 hours of indoor play on carpeted floor	Kissel et al. (1996b), Holmes et al. (1996) (Reported in CSEFH)	6-13 yrs. (n=4) 3-13 yrs. (n=6)	
DSL (1)	Soil Adherence from indoor and outdoor exposure during daycare (four groups of children in day care 3.5, 4, 8, and 8 hours, respectively)	Kissel et al. (1996b), Holmes et al. (1996) (Reported in CSEFH)	1-6.5 yrs. (n=6) 1-6.5 yrs. (n=6) 1-4 yrs. (n=5) 1-4.5 yrs. (n=4)	
DSL (1)	Soil Adherence from 0.67 hours of outdoor soccer	Kissel et al. (1996b), Holmes et al. (1996) (Reported in CSEFH)	13-15 (n=8)	
DSL (1)	Soil Adherence from 4 hours of outdoor gardening	Kissel et al. (1996b), Holmes et al. (1996) (Reported in CSEFH)	16-35 (n=8)	
DSL (1)	Soil Adherence from 11.5 hours of archeological work	Kissel et al. (1996b), Holmes et al. (1996) (Reported in CSEFH)	16-35 (n=7)	
DSL (1)	Soil Adherence from kids playing in mud (2 times for 0.17 and 0.33 hours,	Kissel et al. (1996b), Holmes et al. (1996) (Reported in CSEFH)	9-14 (n=6)	

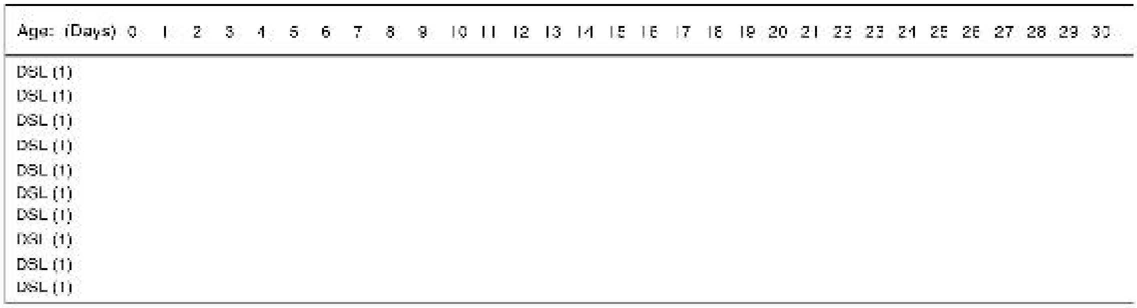


Figure 13a Summary of Available Dermal Contact Data by Days

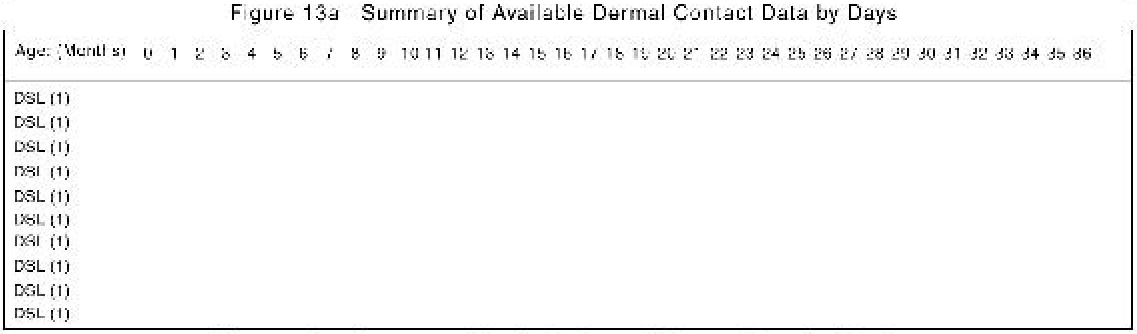


Figure 13b Summary of Available Dermal Contact Data by Months

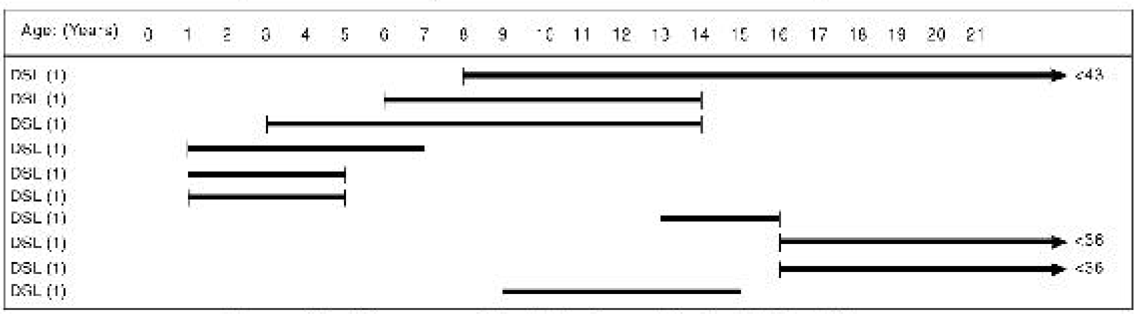


Figure 13c Summary of Available Dermal Contact Data by Years

|—| = Reported within age range

8. Time/activity patterns ($T_{me/ma}$)

Several national and local studies provide data on how children of various ages spend their time in various microenvironments and on various major activities. Table 11 summarizes the age groupings for time/activity pattern data from the studies covered by EPA's CSEFH. Figures 14a-c display these data by age categories.

These data have been reanalyzed to assess the variability in the population for some factors (e.g., Funk et al., 1998 reanalyzed data collected by the California Air Resources Board, as did Hubal et al., 2000). The fact that the data listed below are not independent should be taken into consideration, but it does provide evidence of the availability of the existing data and the different age categories that have and can be used.

One issue associated with time/activity is the need to meet the constraint of 24 hours/day when combining time/activity 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 methods for dealing with this issue.

Similar to other factors discussed in this issue paper, no longitudinal studies exist and all of the time/activity data requires extrapolation from short-term to long-term, which suggests the need for additional study.

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

Exposure Variable	Description	Data Sources	Age groups used for reporting data	Quality and extent of generalization
$T_{me/ma}$ (1)	Average time spent for major activities	Timmer et al., 1985 (Reported in CSEFH)	3-11 yrs. (n=229) 12-17 (n=160)	Quality= Medium Extent of generalization = Medium (data are limited for infrequent activities, but do allow good characterization of major activities)
$T_{me/ma}$ (2)	Average time spent for major activities	Timmer et al., 1985 (Reported in CSEFH)	3-5 yrs. 6-8 yrs. 9-11 yrs. 12-14 yrs. 15-17 yrs.	
$T_{me/ma}$ (3)	Average time spent indoors, outdoors, and in-vehicle and in various activities	Robinson and Thomas, 1991 compared data from the California Air Resources Board study and a national study (Reported in CSEFH)	<12 yrs.	
$T_{me/ma}$ (4)	Average time spent in various micro-environments	Robinson and Thomas, 1991 (Reported in CSEFH)	12-17 yrs. (n=183) 18-24 yrs. (n=250)	
$T_{me/ma}$ (5)	Average time spent in various major activities	Wiley et al., 1991 (Reported in CSEFH)	0-2 yrs (n=313) 3-5 yrs.(n=302) 6-8 yrs (n=269) 9-11 yrs. (n=316)	
$T_{me/ma}$ (6)	Average time spent at home and away from home and level of activity with respect to inhalation exposure	Funk et al, 1998 (Reported in CSEFH)	6-8 yrs. (n=269) 9-11 yrs. (n=316) 12-17 yrs. (n=183)	

$T_{me/ma}$ (7)	Average time spent in various activities	Hubal et al., 2000 (Reported in CSEFH)	0 (n=199) 1 (n=238) 2 (n=264) 3 (n=242) 4 (n=232) 5 (n=227) 6 (n=199) 7 (n=213) 8 (n=226) 9 (n=195) 10 (n=199) 11 (n=206)	
$T_{me/ma}$ (8)	Average time spent indoors and outdoors at home and away from home	Davis et al., 1995 (Reported in CSEFH)	10-60 mo. (n=92)	
$T_{me/ma}$ (9)	Average time spent showering, in the bath, or in the bathroom	Tsang and Kleipis, 1996 (Reported in CSEFH)	1-4 yrs (n=40) 5-11 yrs.(n=139) 12-17 yrs (n=268)	

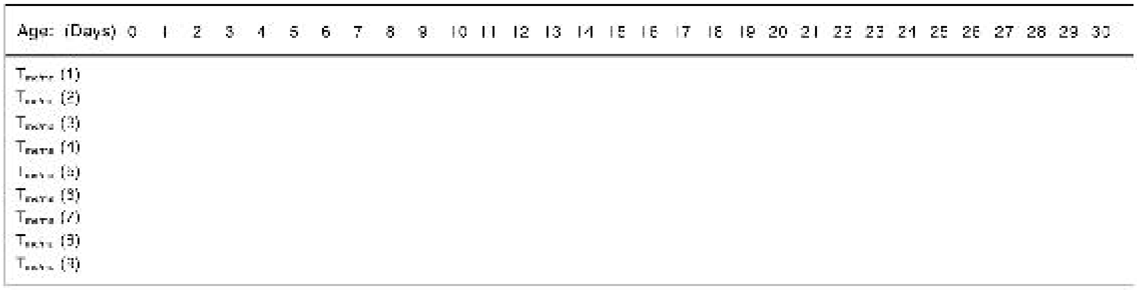


Figure 14a Summary of Available Time/Activity Data by Days

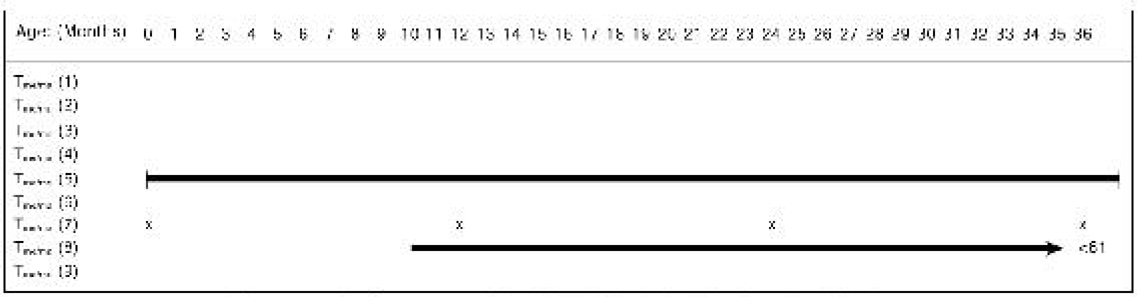


Figure 14b Summary of Available Time/Activity Data by Months

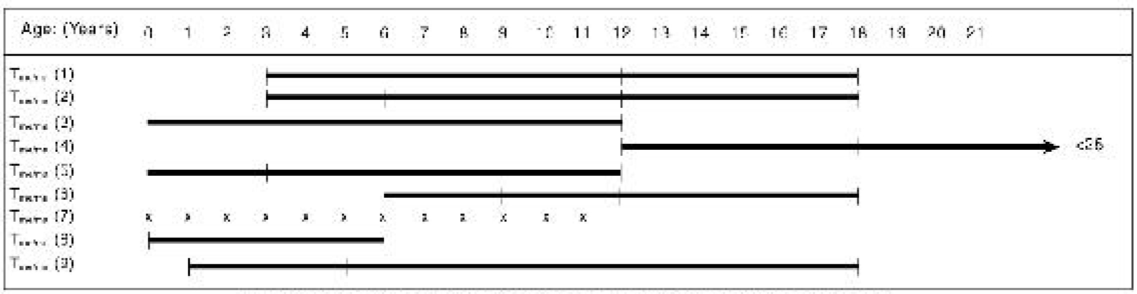


Figure 14c Summary of Available Time/Activity Data by Years

X = Reported at specific age

|—| = Reported within age range

9. Discussion

9.1 Synthesis and observations

As demonstrated in Sections 4 to 8, substantial exposure information is available, but significant gaps in our knowledge still remain. The lack of data in key areas and the representativeness of those data that are available pose key challenges to exposure and risk assessors for children's health, as discussed below.

Representativeness of data

For all the exposure factors discussed, the representativeness of the available data to the individual, population, temporal, and/or spatial scale of interest is an ongoing issue. Not surprisingly, we know the most about children's observable anatomical characteristics, such as body weight 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 anatomical development where 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 2,500 g) and very low birth weight babies (between 1,000-2,500 g) now survive. 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 have changed so dramatically that diary studies of eating habits from 10 years ago might not mention foods that children eat today (e.g., new breakfast cereals, exotic foods). In addition, with the increased globalization of trade, today's children can eat "seasonal" fruits and vegetables nearly all year.

Lack of Data

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 4 through 8 and indicates which of the exposure equations listed in Section 3 use that factor. Note that overall body surface area (SA), the number of fish meals ($N_{fishmeals}$), and the duration of mouthing of objects (T_{mouth}) are not listed in any of Equations 1 through 7 but they do appear in the EPA's Child-Specific Exposure Factors Handbook. 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, which were not discussed in Sections 4 through 8, but which are required in Equations 1 through 7. Note that equations 3 and 4 in particular require many of these factors. 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 often contaminant-specific and medium-specific. They may also depend on the contact mechanics (for which good information about children's activities are needed) and on skin characteristics (which may vary with age). Comparing Tables 12 and 13 suggests the presence of data gaps in the context of assessing dermal exposure. This comparison also clearly shows that very few data exist related to non-dietary intake. In particular, how do children's handling of food impact their exposures, 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?

Table 12: Summary of Physiological and Behavioral Factors Discussed in Sections 4 through 8

Factor	Quality	Extent of generalization	"X" Denotes Used in Equation Number						
			1	2	3	4	5	6	7
BW	H	H							X
SA SA/BW	H	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}		M/L							
$EF_{mouthing}$		M/L						X	
IR_{ma}	M	M	X						
DSL	L	L			X				
$T_{me/ma}$	M	M	X	X					

H=high, M=medium, L=low, H/L=high for average/low for long-term and upper-percentiles
M/L= medium for average/low for long-term and upper-percentiles

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			

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 occur during consumption of food item (events/food item)
$EF_{H/F}$ = frequency of surface to food contact events that occur during consumption of food item (events/food item)
IR_{ma} = the child's respiration rate representing his activity level for that macroactivity (m^3/hr)
DSL = dermal soil loading on surface (mg/cm^2)
DTC_{der} = dermal transfer coefficient for the me/ma (cm^2/hr)
$T_{me/ma}$ = the time spent in that me/ma during the 24 hour period (hr/day)

Figures 15, 16, and 17 show the data available by age category for the exposure factors in Equations 1, 2, 3, 5, and 6. (Equation 4 is not included because so many factors are missing.):

- Figure 15 shows data available for 0 to 30 days (by day). (Note that data are available for only two exposure factors.)
- Figure 16 shows the data available for 0 to 36 months (by month). (Note that data are available for only five exposure factors.)
- Figure 17 shows the data available for 0 to 24 years (by year). (Data are available for 11 exposure factors.)

These figures illustrate the age-related compatability of the available data for applying Equations 1, 2, 3, 5, and 6 (followed by Equation 7 as appropriate to estimate dose). They clearly indicate 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 might also be an issue.

Age: (Days)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
BW	X																												X		
$IR_{breastmilk}$	X	X	X	X	X	X	X	X	X	X	X	X			X							X							X		

Figure 15. Data Available for Ages 0 to 30 Days for Exposure Factors Used in Equations 1, 2, 3, 5, and 6

X = Reported at specific age

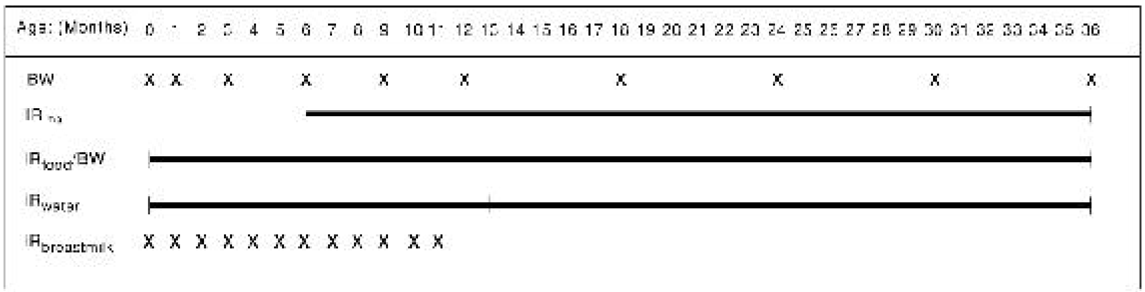


Figure 16. Data Available for Ages 0 to 36 Months for Exposure Factors Used in Equations 1, 2, 3, 5, and 6

X = Reported at specific age

⊢⊣ = Reported within age range

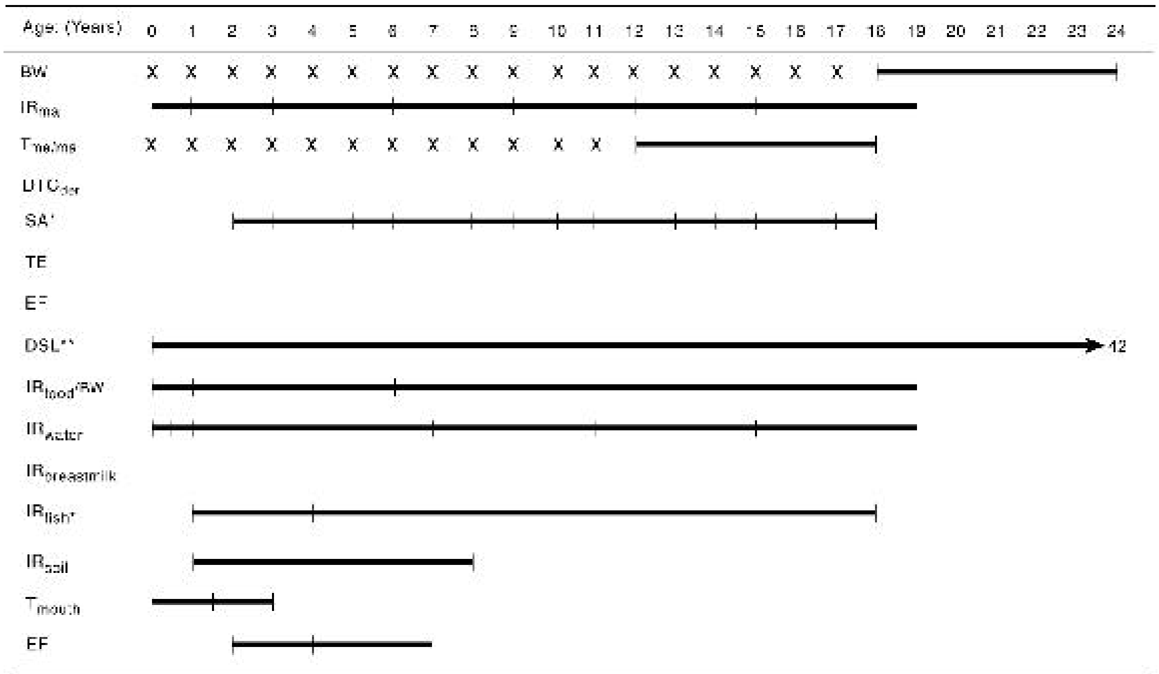


Figure 17. Data Available for Ages 0 to 24 Years for Exposure Factors Used in Equations 1, 2, 3, 5, and 6

* Total body surface area
** Limited data—depends on activity

X = Reported at specific age

= Reported within age range

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 based on short-term data from a wide range of sources. In this context, they must make assumptions about the interindividual variability (i.e., the extent to which the observed differences in daily exposures represent differences between children) and the intraindividual variability (i.e., the extent to which the observed differences in daily exposures represent differences for each child). In reality, both sources of variation probably exist. Unfortunately our ability to characterize them is limited by the lack of repeated samples in longitudinal studies.

9.2 Challenges

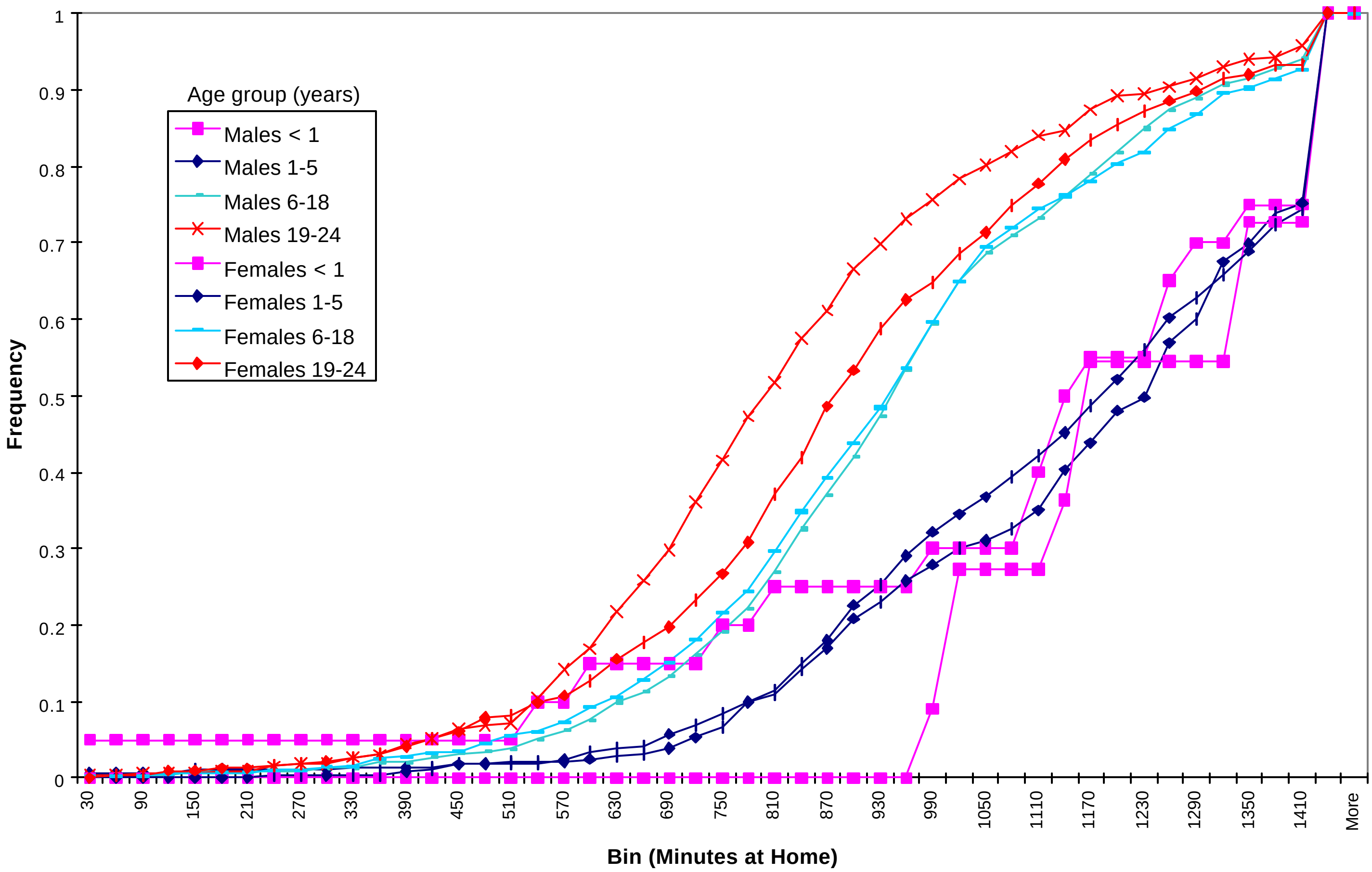
While data are limited, the demand for exposure and risk analysis to inform risk management decisions concerning children's health continues to increase. For most of the exposure factors discussed in this issue paper, some information is available. Significant data gaps remain in the following areas:

- Breast milk consumption by infants today and for children over age 1 year.
- Children's food handling practices and how this leads to exposure (e.g., 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.
- Correlation between exposure factors and growth (i.e., how children's exposure behaviors change over time).

The demand for aggregate exposure assessment and cumulative risk assessment under the Food Quality Protection Act (1996) creates a much greater need for information about correlation between exposure factors and growth and places emphasis on the combined exposures that children experience instead of on their exposure from a single pathway. Currently the greatest challenge lies in combining the data from various independent studies in a way that appropriately models the experiences of real American children.

Analysts building models to estimate aggregate exposure have already had the experience of assessing and dealing with the inconsistencies of the age categories for children (Personal communication with Paul Price and Chris Chaisson, 2000). For example, in building Lifeline™ (a model being developed to estimate aggregate exposure from pesticides), Price and Chaisson evaluated all the existing data bases to explore where the natural breakpoints of age categories occur in the data. In one example, for the time activity factor of time spent at home, they found four age ranges that correspond to infancy (0-1 year), pre-school children (1-5 years), school-age children (6-18 years), and post school-age children (>18 years) as the relevant categories. Figure 18 shows the distributions of data for these factors in these age categories for both genders.

Figure 18: NHAPS Data on Time Spent at Home for Males and Females in Four Age Groups
(Source: The LifeLineTM Project)



Notably, gender does not appear to be significant. Although these 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 microenvironments, although videography studies and other new methods provide a means for collecting these data. In addition, how school-age children spend their time in summer months and after school is relatively uncertain. The advantage that models like the Lifeline™ model have over traditional exposure models is their ability to track the child over the smallest relevant time unit (e.g., exposure over a day) and to build longer exposures based on cumulating these units. . This is just one example, and the same issue would apply in the development of other aggregated exposure models like Calendex™, the Cumulative and Aggregate Exposure Risk Evaluation System (CARES), MENTOR, Stochastic Human Exposure and Dose Simulation (SHEDS), and the Total Risk Integrated Methodology (TRIM).

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. The most significant challenges to modelers come from extrapolating the existing data to project short-term data to longer-term averages required for the evaluation of chronic hazards and dealing with the existing data gaps.

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