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Identifying Childhood Age Groups for Exposure Assessments and Monitoring

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The purpose of this article is to describe a standard set of age groups for exposure assessors to consider when assessing childhood exposure and potential dose to environmental contaminants. In addition, this article presents examples to show how the age groups can be applied in children's exposure assessments. A consistent set of childhood age groups, supported by an underlying scientific rationale, will improve the accuracy and comparability of exposure and risk assessments for children. The effort was undertaken in part to aid the U.S. Environmental Protection Agency (EPA) in implementing such regulatory initiatives as the 1997 Presidential Executive Order 13045, which required all federal agencies to ensure that their standards take into account special risks to children. The standard age groups include: birth to <1 month; 1 to <3 months; 3 to <6 months; 6 to <12 months; 1 to <2 years; 2 to <3 years; 3 to <6 years; 6 to <11 years; 11 to <16 years; and 16 to <21 years. These age groups reflect a consideration of developmental changes in various behavioral, anatomical, and physiological characteristics that impact exposure and potential dose. It is expected that the availability of a standard set of early-life age groups will inform future analyses of exposure factors data as well as guide new research and data collection efforts to fill knowledge gaps.

KEY WORDS: Age groups; children; exposure assessment; life stages; risk assessment

1. INTRODUCTION

Children's exposures to environmental toxicants may be different from those of an adult when placed in the same setting due to differences in physiology and behavior. They consume more of certain foods and water and have higher inhalation rates per kilogram of body weight than adults. For example, consumption of apples by children between birth and five months of age is about 19 g/kg-day, while consumption by adults 20 years and older is approximately 2 g/kgday, almost a 10-fold difference.(1) Young children play close to the ground and come into contact with contaminated soil outdoors and with contaminated dust on surfaces and carpets indoors. They also display more hand/object-to-mouth activity than adults. As another example, exposure to chemicals in breast milk impacts only infants and young children. While these differences have led many to note that "children are not small adults," it is clear that this simplification is inadequate to describe how behavioral and physiological changes early in life can have a profound impact on exposure.

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In 1993, the National Academy of Sciences (NAS) issued a report, *Pesticides in the Diets of Infants and Children,* which highlighted many important differences between children and adults with respect to exposure to and risks posed by pesticides.(2) The NAS report provided the impetus for the President's Executive Order 13045, *Protection of Children from Environmental Health Risks and Safety Risk,* which stated that "each Federal agency: shall ensure that its policies, programs, activities, and standards address disproportionate risks to children that result from environmental health risks or safety risks."(3) In response to this executive order, EPA and other federal agencies have been investigating ways to improve risk assessments for children.

Prior to the release of the revised Guidelines for Carcinogen Risk Assessment,(4) the EPA often described all types of subgroups of individuals as subpopulations. The Revised Cancer Guidelines recognized that it is helpful to distinguish between subgroups that form a relatively fixed portion of the population (e.g., subgroups based on ethnicity) and subgroups such as age groups that are potentially inclusive of the entire population over time. Therefore, in this article childhood is viewed as a sequence of life stages, and as such, treats age subgroups of children as life stages and not subpopulations. The term "life stage" refers to a distinguishable timeframe in an individual's life characterized by unique and relatively stable behavioral and/or physiological characteristics that are associated with development and growth. Although the gestational period is an important life stage, it is beyond the scope of this article.

Since childhood is a time of rapid behavioral and physiological changes, it is important that exposure assessments reflect these significant differences. A major issue facing risk assessors is how to consistently consider age-related changes in behavior and physiology when assessing early life stage exposure and potential dose.(5) This issue is critical for scientists involved in preparing exposure assessments applicable to children and for use in evaluating integrated lifetime exposures. Currently, there is no consistent age under which individuals are classified as youth or children. In some cases, individuals under age 21 are considered children, while in other cases age 18 is used as the limit. Furthermore, how to subdivide this group in a consistent and scientifically supported manner has been somewhat elusive.

Historically, expert judgment has been used to create age groups that capture periods of potentially high exposure or unusual exposure patterns (e.g., the frequency and duration of mouthing hands and objects for infants and toddlers). In some cases, expert judgment has been applied to capture vulnerable periods of development or critical windows when exposure to an environmental contaminant may be particularly damaging to a specific physiologic system (e.g., the effects of lead on hemoglobin due to age-related differences in iron deficiency). In many cases, the selection of age groups by exposure and risk assessors has been heavily influenced by the quality and quantity of existing data to support the development of exposure and potential dose estimates. Other factors that have been considered to select age groups include: specific study objectives, methodological limitations, ease of collecting specimens or exposure measurements, and ethical considerations. Table I presents an example of available data on children's mouthing behavior. This table shows the differences in the way in which researchers present study results. This case-by-case application of expert judgment has led to variations in the specific age groups considered for assessing childhood exposure. These variations in the presentation of exposure data varying by age group has often made it difficult to compare and/or integrate the data from different studies.

The standard age groups presented in this article were developed by EPA based on the results of a peer involvement workshop(17) sponsored by U.S. EPA focused on developmental changes in behavior and physiology impacting exposures to children combined with subsequent EPA analysis of existing exposure factors data.(18) Results of these efforts culminated in a recommended set of age groups and guidance for applying these.(6) The standard age groups are summarized in Table II and the associated guidance is provided in EPA's report entitled *Guidance for Selecting Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants*.(6) This article describes EPA's development of the recommended set of age groupings and subsequent EPA analysis of exposure factors data. Two case studies are also presented as examples to demonstrate how the age groups are applied for purposes of designing exposure monitoring studies and conducting exposure assessments focused on children.

2. METHODS

As an initial step in the development of a recommended set of children's age groups, a peer involvement workshop was held in 2000 to bring together scientific experts in the areas of child development and exposure assessment to answer the question of how knowledge of behavioral, anatomical, and

Table I. Summary of Children's Mouthing Behavior Data

	Mean Mouthing Frequency/Time				
Age (months)	Hand-to-Mouth	Object-to-Mouth	Total	Population Size	Reference
10–60			55 minutes/day	92	7
2.5–4.2 years	9 contacts/hour			4	8
3–6			37 minutes/day	5	9
6–12			44 minutes/day	14	
12–18			16 minutes/day	12	
18–36			9 minutes/day	11	
2–6 years	9.5 contacts/hour	16.3 contacts/hour	25.8 contacts/hour	30	10
3–4 years	4 contacts/hour	6 contacts/hour	10 contacts/hour	3	11
5–6 years	8 contacts/hour	1 contacts/hour	9 contacts/hour	7	
7–8 years	5 contacts/hour	1 contacts/hour	6 contacts/hour	4	
10–12 years	4 contacts/hour	1 contacts/hour	5 contacts/hour	5	
0–18		70 minutes/day		146	12
18–36		56 minutes/day		40	
3–12	2.4 minutes/hour; 26 minutes/day		70 minutes/day	64	13
12–24	1.7 minutes/hour; 18 minutes/day		48 minutes/day	60	
24–36	1.2 minutes/hour; 12 minutes/day		37 minutes/day	45	
<24	18 contacts/hour	62 contacts/hour	81 ± 7 contacts/hour	28	14
>24	16 contacts/hour	26 contacts/hour	42 ± 4 contacts/hour	44	
1–3	50 minutes/day[a]	29 minutes/day	79 minutes/day	9	15
3–6	96 minutes/day[a]	132 minutes/day	228 minutes/day	14	
6–9	77 minutes/day[a]	251 minutes/day	328 minutes/day	15	
9–12	98 minutes/day[a]	156 minutes/day	254 minutes/day	17	
12–15	36 minutes/day[a]	157 minutes/day	193 minutes/day	16	
15–18	39 minutes/day[a]	136 minutes/day	175 minutes/day	14	
18–21	80 minutes/day[a]	99 minutes/day	179 minutes/day	16	
21–24	113 minutes/day[a]	142 minutes/day	255 minutes/day	12	
2 years	148 minutes/day[a]	304 minutes/day	452 minutes/day	39	
3 years	199 minutes/day[a]	179 minutes/day	378 minutes/day	31	
4 years	171 minutes/day[a]	96 minutes/day	267 minutes/day	29	
5 years	543 minutes/day[a]	64 minutes/day	607 minutes/day	24	
18–24	74 contacts/hour; 11 minutes/hour indoor	11 contacts/hour; 0.4 minutes/hour indoor	85 contacts/hour; 11 minutes/hour indoor	1	16
	7 contacts/hour; 0.4 minutes/hour outdoor	7 contacts/hour; 0.4 minutes/hour outdoor	14 contacts/hour; 0.8 minutes/hour outdoor	8	
25–32	13 contacts/hour; 0.7 minutes/hour indoor	6 contacts/hour; 0.2 minutes/hour indoor	19 contacts/hour; 0.9 minutes/hour indoor	8	
	9 contacts/hour; 0.2 minutes/hour outdoor	6 contacts/hour; 0.4 minutes/hour outdoor	15 contacts/hour; 0.6 minutes/hour outdoor	30	
7–12	20 contacts/hour	24 contacts/hour	44 contacts/hour	13	17
13–24	16 contacts/hour	10 contacts/hour	26 contacts/hour	12	
25–36	12 contacts/hour	8 contacts/hour	20 contacts/hour	18	
37–53	22 contacts/hour	10 contacts/hour	32 contacts/hour	9	

[a] Includes finger/thumb sucking.

physiological changes in children can guide the development of a generic set of age groupings. The workshop was a public meeting attended by an invited panel comprised of 22 experts in toxicology, exposure assessment, risk assessment, and pediatrics from universities, state and federal government, industry, and medical centers. Table III lists the panel members who participated in the workshop.

Table II. Proposed Childhood Age Groups for EPA Exposure Assessments(6)

Age Groups <1 Year[a]	Age Groups ≥1 Year
Birth to <1 month	1 to <2 years
1 to <3 months	2 to <3 years
3 to <6 months	3 to <6 years
6 to <12 months	6 to <11 years
	11 to <16 years
	16 to <21 years[b]

[a] For purposes of evaluating exposure or potential dose but not internal dose, it may be reasonable to combine some of these groups (e.g., the first three groups could be combined to encompass "birth to < 6 months").

[b] To be considered on a case-by-case basis.

To organize the workshop discussion, participants were divided into two subgroups according to their specific areas of expertise. One subgroup discussed behavioral development, while the other focused on physiology and anatomical growth. Participants were asked to focus their discussion on those aspects of development particularly relevant to exposure and potential dose, not to toxicity. The discussions revealed that workshop participants preferred assessment approaches that could incorporate childhood development as a continuous function. However, recognizing the paucity of existing data, the participants concluded that a standard set of age groups (or bins) can be useful as guides for the development of environmental exposure scenarios. To that end, the workshop participants offered some preliminary advice on possible age groups related to developmental change. A compilation of the experts' discussion regarding behavioral and physiological characteristics that led to the development of these particular age groups is presented in Table IV. The discussions resulted in two sets of recommended early life stage age groupings, one based on behavioral considerations and the other based on anatomical and physiological changes in children. While prenatal development was outside the scope of the workshop discussions, participants unanimously stressed the importance of including this life stage in exposure and risk assessments. A summary of the workshop discussions is detailed in the document: *Summary Report of the Technical Workshop on Issues Associated with Considering Developmental Changes in Behavior and Anatomy when Assessing Exposure to Children.*(18)

Following the workshop, an EPA technical panel reviewed the two sets of recommendations, as well as

Table III. Participants in Technical Workshop on Issues Associated with Considering Developmental Changes in Behavior and Anatomy when Assessing Exposure to Children—List of Participants(17)

Kimberly Thompson – Workshop Chair, Harvard Center for Risk Analysis

Anatomy Group	Behavior Group
Thomas Armstrong ExxonMobil Biomedical Sciences, Inc.	Deborah Bennett Lawrence Berkeley National Laboratory
Sophie Balk Montefiore Medical Center	Richard Fenske University of Washington
Jim Bruckner University of Georgia	Lynn Goldman Johns Hopkins
Michael Dinovi U.S. Food and Drug Administration	Celestine Kiss U.S. Consumer Product Safety Commission
Gary Ginsberg Connecticut Department of Public Health	Bruce Lanphear University of Cincinnati
Robert Johnson Agency for Toxic Substances and Disease Registry	James Leckie Stanford University
John Kissel University of Washington	Mary Kay O'Rourke University of Arizona
Melanie Marty California Environmental Protection Agency	P. Barry Ryan Emory University
George Rodgers University of Louisville	Katherine Shea Consultant
Margo Schwab Johns Hopkins	Robin Whyatt Columbia University
William Weil Michigan State University	

Table IV. Examples of Characteristics Considered in Deriving the Recommended Set of Childhood Age Groups

Age Group	Characteristics
Birth to <1 month	*Behavior-Related:* Time spent sleeping or sedentary; breast and bottle feeding *Physiology-Related:* Rapid growth and weight gain; increasing proportion of body fat; high skin permeability; high oxygen requirements (increased breathing rate); deficiencies in hepatic enzyme activity; immature immune system; more alkaline stomach; increases in extracellular fluid; renal function less than predicted by body surface area
1 to <3 months	*Behavior-Related:* Time spent sleeping or sedentary; breast and bottle feeding *Physiology-Related:* Rapid growth and weight gain; increasing proportion of body fat; high oxygen requirements (increased breathing rate); deficiencies in hepatic enzyme activity; immature immune system; more alkaline stomach; increases in extracellular fluid; renal function less than predicted by body surface area
3 to <6 months	*Behavior-Related:* Solid foods may be introduced into diet, especially toward the end of this stage; contact with surfaces increases; mouthing of hands and objects increases; more time spent in breathing zone close to floor *Physiology-Related:* Rapid growth and weight gain; increasing proportion of body fat; deficiencies in hepatic enzyme activity; immature immune system functions; increases in extracellular fluid; renal function less than predicted by body surface area
6 to <12 months	*Behavior-Related:* Food consumption expands; floor mobility increases (surface contact); children are increasingly likely to mouth nonfood items; children develop personal dust clouds *Physiology-Related:* Rapid growth and weight gain; body fat increases begin to moderate; deficiencies in hepatic enzyme activity; immature immune system; rapid decrease in extracellular fluid; can begin predicting renal function by body surface area
1 to <2 years	*Behavior-Related:* Full range of foods consumed; participation in increased play activities coupled with extreme curiosity and poor judgment; breast and bottle feeding cease; children walk upright, run, and climb; children occupy a wider variety of breathing zones and engage in more vigorous physical activities; frequency of mouthing hands and objects is high *Physiology-Related:* Some hepatic enzyme activities peak at a level exceeding adult's; most immune system functions have matured; extracellular fluid becomes more consistently related to body size
2 to <3 years	*Behavior-Related:* Frequency of mouthing hands and objects begins to moderate; occupancy of outdoor spaces increases; children begin to wear adult-style clothing *Physiology-Related:* Hepatic enzyme activity level falls back to the adult range
3 to <6 years	*Behavior-Related:* Continued increases in the occupancy of outdoor spaces *Physiology-Related:* Entering a period of relatively stable weight gain and skeletal growth (as opposed to a period marked by growth spurts)
6 to <11 years	*Behavior-Related:* Decreased oral contact with hands and objects as well as decreased dermal contact with surfaces; children spend time in school environments and begin playing sports *Physiology-Related:* Period of relatively stable weight gain and growth but may be entering period of rapid reproductive and endocrine system changes (especially for females)
11 to <16 years	*Behavior-Related:* Smoking may begin; increased rate of food consumption; increased independence (more time out of home); workplace exposures can begin *Physiology-Related:* Rapid skeletal growth; rapid reproductive and endocrine system changes
16 to <18 years	*Behavior-Related:* High rate of food consumption; independent driving begins; expanded work opportunities *Physiology-Related:* Rapid skeletal growth (may see epiphyseal closure); rapid reproductive and endocrine system changes
18 to <21 years	*Behavior-Related:* High rate of food consumption; increased time in work environments; may move away from home environment *Physiology-Related:* Reproductive growth continues (especially for males); epiphysial closure may take place

Note: Table adapted from *Summary Report of the Technical Workshop on Issues Associated with Considering Developmental Changes in Behavior and Anatomy when Assessing Exposure to Children*.(17) Many of the behavioral and physiological characteristics listed in this table are repeated across age groups (especially for ages up to <12 months; e.g., rapid growth and weight gain). In determining the range of ages to include in a particular age group, the rate of change in these characteristics was often a key factor considered.

available exposure factors data (e.g., food consumption rates, breathing rates, etc.), and developed a single set of recommended age groups.(6) This final set was then compared to the data gathered in developing EPA's *Child-Specific Exposure Factors Handbook* to identify data gaps.(7) Resulting recommendations for further research to improve the database for childhood exposure are summarized in Table V.

Additionally, two case studies were developed to explore the implications of applying the recommended age groupings when conducting an exposure assessment. The first case study examines estimates of

Table V. Summary of Recommendations for Further Analysis and Research on Exposure Factors Data for Children

Exposure Factor	Recommendation for Further Analysis and Research
Breast milk intake	• Collect data on the distribution of breast milk intake across the U.S. population including major ethnic groups • Collect data on maternal nutrient status and its effect on the fat content of breast milk • Collect data on prevalence and duration of breast feeding
Food intake	• Analyze the combined 1994–1996 and 1998 Continuing Survey of Food-Intake by Individuals (CSFII) to develop estimates for the recommended childhood age groups (implemented) • Conduct research on the contamination of food resulting from contact with surfaces and hands
Water intake	• Analyze the combined 1994–1996 and 1998 Continuing Survey of Food-Intake by Individuals (CSFII) to develop estimates for the recommended childhood age groups (implemented)
Soil ingestion	• Collect soil ingestion data on a broader range of childhood ages (e.g., 3 months to <13 years) • Collect data that would allow estimation of variability and distributions of soil intake across geographic areas, race, economic status, and other demographic variables • Collect data that would allow the characterization of seasonal variation in soil intake; these data would support the development of distributional information for long-term exposures • Explore new approaches to interpreting soil ingestion data
Nondietary ingestion	• Systematic, probability-based studies of microactivities should be undertaken that address a broad range of childhood age groups (at least to <6 years of age)
Inhalation rate	• The more recent CSFII data should be analyzed further to obtain food energy intake/energy expenditures for the recommended set of childhood age groups (studied, but other methodology was deemed more appropriate) • For short-term, activity-specific inhalation rate estimates, the approach of Allan and Richardson (1998) could be explored further but would need to be supported with the collection of additional activity data for children(20) • Activity-specific inhalation rate estimates could also be developed using the Layton (1993) approach as modified by McCurdy (2000); specifically, inhalation is calculated in the manner described by Layton but energy expenditure is estimated using a factorial approach in which an individual's activities are assigned energy expenditure values based on a multiplier of basal metabolic rate (termed a MET); daily estimates of energy expenditure derived from this method could be compared to estimates derived from the CSFII to lend insight into quality assurance issues (implemented)(21,22) • A critical area of research (especially for children up to <5 years of age) is the collection of ventilatory equivalence data for children; data collection efforts should consider susceptible populations such as asthmatic children
Activity patterns	• Analyze the most current version of the Consolidated Human Activity Database (CHAD) for activity pattern data applicable to the recommended age groups • Develop methods for monitoring children's macroactivities • Develop guidance for the collection of microactivity data • Collect population-based data on children's macroactivities and exposures to allow characterization as a function of age, gender, environmental setting (microenvironments), socioeconomic status, race/ethnicity, geographic location, and season; in particular, focus on young children (less than 4 years of age) and children aged 11 years and older
Skin surface area	• Update skin surface area estimates for children 2 years of age and older using the newer NHANES III data for height and weight; the analyses should support the recommended set of childhood age groups (implemented using NHANES 99+) • Collect new height and weight data for children less than 2 years of age (for use in regression equations for determining skin surface area) (implemented using NHANES 99+) • More detailed studies of soil adherence to skin need to be conducted to determine variations among individuals and the effects of duration of activity, clothing use, and time of year on this factor • Explore the use of skin surface area in normalizing exposure estimates
Body weight	• Further statistical analysis of the NHANES III data should be conducted to allow the derivation of multiple percentiles and distributional information for the recommended set of childhood age groups (implemented using NHANES 99+) • The NHANES III data should be analyzed further to develop body weight estimates that are specific for selected ethnic groups • In addition to the relationship between age and weight, the existing data should be analyzed for other relationships (e.g., age and stature, body mass index, etc.) to develop a more complete understanding of body metrics that may have a bearing on exposures, doses, and risks

Note: Recommendations for future research were extracted and updated from age group recommendations for assessing childhood exposure and the adequacy of existing exposure factors data for children. Technical Issue Paper.(19)

dietary exposure and the impact of splitting or combining age groups on the results. The second case study provides an example of assessing children's nondietary exposures where exposure data are limited.

2.1. Case Study 1: Comparison of Dietary Exposure Estimates Using Separate and Combined Age Groupings for 0 to <3 Year-Olds

A probabilistic human exposure model was applied using food consumption information from the U.S. Department of Agriculture's (USDA) Continuing Survey of Food Intakes by Individuals (CSFII) and the USDA's Pesticide Data Program (PDP) pesticide residue data.(23,24) It is important to note that this example assessment does *not* represent or reflect an actual EPA risk assessment. Although the residues are based upon actual PDP data, the pesticide in this example will be referred to as "pesticide x"; the relevant information here is the potential difference in exposure estimates using the standard age groups versus combined groupings.

The nationally representative CSFII survey database includes information on two-day food intakes by 20,607 individuals of all ages for the combined years of 1994–1996 and 1998. More details about how this survey is conducted are found elsewhere.(23) CSFII also contains representative recipes for foods found in the Food Coding Database. Applying the recipes to the foods consumed provides individual information on raw agricultural commodities (RAC) consumed. The RAC intake information can be combined with RAC residue data to provide estimates of dietary exposure.(23)

The dietary module of EPA's Stochastic Human Exposure and Dose Simulation (SHEDS) model was applied to calculate dietary pesticide x exposure for each of the age groupings.(25) The basic equation used by SHEDS to estimate the average daily dose of dietary exposure is:

$$\text{Dietary Exposure} = \sum_i (\text{Food Item}_i^{*}\text{Residue Level}_i),$$

where Dietary Exposure = mass of the chemical ingested over the day by an individual; Food Item$_i$ = mass of the i^{th} food item consumed on a given day; and Residue Level$_i$ = the level of the chemical residue in i^{th} food item.

For each simulation SHEDS draws a diary from the CSFII database to obtain the amount of each food item that an individual consumes on a given day. The USDA recipe files are applied to each food in the CSFII Food Coding Database to break the foods consumed into their RACs. The residue level for each RAC is randomly sampled by SHEDS from a distribution of residues for each food item provided in the PDP database.

2.2. Case Study 2: Ingestion of Contaminated Soil by Young Children

This case study provides an example using the standard age groupings for an exposure pathway for children, for which there are limited exposure data. The example emphasizes the need for the collection of data for some of the selected age groups. The soil intake rate values used in this case study should not be considered EPA recommendations, but rather they are provided as an example of the thought process involved in determining the need to address a particular age group. Also, this case study does not consider children exhibiting pica behavior.

The assumptions used for soil ingestion rates are based on study data presented in the EPA's *Child-Specific Exposure Factors Handbook* and other more recent information. However, the original studies do not address the same age ranges as the recommended age groupings. The raw study data were not available. Therefore, information on hand-to-mouth frequency was analyzed and used as a surrogate to examine differences in soil ingestion among age groups. The assumption is that there is a positive correlation between mouthing behavior and soil ingestion.

The studies used in this soil ingestion example are summarized in Table VI. These are based on mass balance calculations using tracer elements found in soil, which are poorly absorbed by the body. The age range of the children included in the studies was 1–7 years old. The mean values ranged from 38 mg/day to 193 mg/day with a weighted average of 90 mg/day for soil ingestion and 106 mg/day when it is considered that a portion of the soil ingested comes from dust. These estimates are based on weighted averages using aluminum and silicon as tracers, except for Calabrese *et al.* (1997), which uses the best tracer methodology.(30) These tracer elements were considered the most reliable based on a review of the current literature. Results obtained using titanium as a tracer were not considered in this calculation because titanium exhibits greater variability compared to other tracers.

Data for children <1 year of age are not available. However, infants at birth to 6 months old are unlikely to be exposed to outdoor soils since they may

Table VI. Summary of Estimates of Incidental Soil and Dust Ingestion by Children (1–7 Years Old) (mg/day)[a]

Sample Size	Age (Years)	Source	Mean	P25	P50	P75	P90	P95	Reference
101	2–7	Soil	61		42				26
		Soil and dust	112		82				
64	1–4	Soil	131	8	31	84	169	239	27
162	1–7	Soil	104	10	37	80	156	217	28
64[b]	1–3	Soil	66	2	20	69	224	283	30
		Dust only[c]	127	–	27	198	559	614	
		Soil and dust[d]	97		24	134	392	449	
12	3–7	Soil	38						29
Weighted average	1–7	Soil	90	8	35	78	174	236	
		Soil and dust	106		60	134	392	449	

[a] Using the average of Al and Si as tracers (except otherwise specified under note "b").
[b] Using the best tracer method.
[c] Calculated assuming all the ingestion originated from dust.
[d] Calculated by averaging the "soil" and "dust only" rows.

have limited mobility. Very young infants may sleep for hours during the day and therefore their chances to become in contact with contaminated soil and dust may be very low. Some mouthing of objects and hands are likely to occur and therefore indoor dust ingestion may be a concern. This exposure is expected to be lower compared to older children who may be crawling and spending some time outdoors. Children 6- to 12-months old may be exposed to both indoor dust and outdoor soils. However, we hypothesize that their exposure is lower than children between the ages 1 to 6 years of age because their opportunities for exposure and the duration of that exposure are lower. Thus, this case study example only considers nonpica behavior exposures to children 1 to <2 years, 2 to <3 years, 3 to <6 years, and 6 to <11 years.

To examine these age groupings, three studies containing raw hand-to-mouth frequency data were analyzed to determine whether statistical differences exist among the recommended age groups for children ages 1–6 years. The studies examined included Leckie *et al.* (2000), Zartarian *et al.* (1998), and Tulve *et al.* (2002).(13,31,32) These were selected because raw data were readily available. When data from the three studies were combined, there were nine data points for 6 to <12 months, 98 data points for 1 to <2 years, 80 data points for 2 to <3 years, 161 data points for 3 to < 6 years, and 3 data points for 6 to <11 years.

Potential dose via this pathway can be calculated as follows:

$$LADD_{\text{POT soiling}} = \frac{C_{soil} * CF * IR_{soil} * EF * ED}{BW * AT},$$

where: $\text{LADD}_{\text{POT soiling}}$ = potential lifetime average daily dose from ingestion of soil (mg/kg-day); C_{soil} = concentration of contaminants in soil (mg/g), assumed to be 0.001 mg/g; CF = conversion factor for 0.001 g/mg; IR_{soil} = ingestion rate of soil (mg/day); EF = exposure frequency (days/year), assumed to be 350 days a year for this example because the soil/dust intake rate used is an annual average intake rate; young children are assumed to be away from the source of contamination (e.g., on vacation) for two weeks per year;(33) ED = exposure duration (years), exposure duration of 1 year is used for the first two age groups (1 to <2, 2 to <3 years), 3 years of exposure for the 3 to <6 years of age, and 5 years of exposure for the 6 to<11 years of age, BW = average body weight (kg), for children between the ages of 1 and 2 years is 12 kg, for 2 to <3 years, 14 kg, for 3 to <6 years, 18 kg, and for 6 to <11 years, 31 kg,(19) and AT = averaging time (days), assuming that the contaminant is results in a noncarcinogen, the averaging time is the same as the exposure duration.

3. RESULTS

3.1. General Results

Results of the efforts described above culminated in a recommended set of age groups and guidance for applying these (Table II). The recommended age groups are based on exposure considerations only and, as such, are not intended to take into account chemical-specific toxicological variability that can also impact risk; such considerations should occur through an iterative dialogue between exposure assessors and toxicologists.

3.2. Results of Case Study 1

Table VII provides summary statistics for dietary pesticide *x* exposures by the recommended age groups

Table VII. Summary of Dietary Pesticide *x* Exposures (ug/kgday) by Recommended Age Groupings

Age Group	*N*	Mean	std	P5	P25	P50	P75	P95
Birth to <1 month	150	1.4E−03	1.4E−02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
1–2 months	436	3.4E−03	1.9E−02	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.4E−02
3–5 months	826	1.9E−02	5.2E−02	0.0E+00	0.0E+00	0.0E+00	1.5E−02	1.0E−01
6–11 month	1,472	4.9E−02	6.8E−02	0.0E+00	5.1E−03	2.6E−02	6.7E−02	1.8E−01
1 to <3 years	4,287	8.5E−02	9.6E−02	7.0E−03	3.2E−02	6.3E−02	1.1E−01	2.3E−01
1 year	2,124	9.0E−02	9.5E−02	8.4E−03	3.8E−02	6.9E−02	1.1E−01	2.4E−01
2 years	2,163	8.1E−02	1.2E−01	6.3E−03	2.8E−02	5.5E−02	1.0E−01	2.2E−01
3–5 years	8,970	6.1E−02	9.4E−02	5.4E−03	2.0E−02	4.1E−02	7.5E−02	1.7E−01
6–10 years	3,419	3.4E−02	5.5E−02	2.6E−03	1.1E−02	2.2E−02	4.0E−02	9.4E−02
11–15 years	2,056	1.7E−02	3.4E−02	5.8E−04	4.3E−03	1.0E−02	2.0E−02	5.0E−02
16–20 years	1,542	1.2E−02	2.7E−02	1.7E−04	1.9E−03	5.9E−03	1.4E−02	4.1E−02

in terms of ug/kgday. Results of nonparametric statistical methods (Kruskal Wallis and Wilcoxon tests) revealed that there are no statistical differences, based on 95th percentiles, for dietary "pesticide *x*" exposure for children aged 1 to <3 years compared to each of children 1 to <2 years and children 2 to <3 years. However, there are significant statistical differences, based on 50th percentiles for children aged 1 to <3 years compared to each of children 1 to <2 years and children 2 to <3 years (the highest exposed group is 1 to <2 years, followed by 1 to <3 years, followed by 2 to <3 years, as shown in Table V). The degree of statistical difference for exposures among age groups when a large sample size is available could be considered along with toxicological differences in deciding appropriate groupings for a risk assessment. In this particular case, the statistical difference is significant at the median but not the 95th percentile.

The analyses also revealed significant statistical differences between the <1 year age grouping and each of the individual age groups <1 year (i.e., birth to <1 month; 1 to <3 months; 3 to <5 months; 6 to <12 months) at both the median and 95th percentiles. The reason for this is that the dietary exposure for the 6- to <12-month-olds is higher than the other age groupings less than 6 months. However, the PDP residue data for breast milk are not available and therefore not included in this analysis. Thus, a key component of early-life exposure is not considered in this example. These results indicate the importance of not lumping data together in some cases when sufficient data are available, and the importance of using the recommended age groupings, especially for very young children.

In Case Study 1, biases are introduced when combining age groups, especially for the < 1 year-olds. The uncertainties associated with this exposure assessment example include the following:

- the assumption that the data on food ingestion in the CSFII database are representative of the intakes for children in those age groups;
- the assumption that the PDP data are representative and cover all foods containing pesticide *x* residues;
- the assumption of 0 for nondetects in the PDP database;
- the assumption that processing of food has no effect on the residues of RACs in the foods consumed;
- the assumption that the recipe files used to break foods consumed into their RACs are accurate;
- the assumption that PDP data used are relevant to individuals in CSFII from different geographic regions; and
- the lack of breast milk PDP data results in a tacit assumption that this pathway has no impact on early-life exposure.

This particular example involves a pesticide that was used on a large variety of crops. Other examples involving residues on a more limited number of foods would be expected to yield different quantitative results. Nevertheless, this example does illustrate the impact of incorporating age group binning in exposure assessment.

3.3. Results of Case Study 2

Results of the nonparametric Wilcoxon statistics method revealed that the hand-to-mouth frequency in the 1 to <2 year group are higher than the 2 to <3 year group and the 3 to <6 year group with statistical significance. Conclusions cannot be made about the 6 to <12 months and 6 to <11 year age groups because the sample sizes were too small. The fact that there is a statistical difference for at least the 1-year-olds and the other age groups emphasizes the need for data collection specific to the recommended age groups.

Given that the mouthing behavior data for the 1 to <2-year-olds showed a higher frequency for this group than the 2 to <3 and the 3 to <6-year-old groups, it may be reasonable to assume a higher ingestion rate for this age group. It is reasonable to assume that the upper end of the range of means presented in Table VI relates to the younger children in the study (i.e., 1 to 2 years old). Since the reported data in Table VI have been lumped into bigger age categories (e.g., 2–7 years old) and the raw data were not available, it is not possible to examine age-related differences among children. Considering the uncertainties with the available soil ingestion data, this scenario assumes an ingestion rate of 100 mg/day for children in all the recommended age categories. This value is the weighted average estimates found in the literature for children 1 to 7 years old. However, this may overestimate exposures through this pathway for the 6 to <11 years olds. Although the frequency of mouthing behavior for children 2 to <3 years may be less than for the 1 to <2 year-olds, their opportunities for soil contact are higher because they spend more time in recreational activities than the younger age group.(34) Therefore, a 100 mg/day ingestion rate was also assumed for this age group.

The example presented here is used to represent a method of estimating the potential dose among a population of children, ages 1 to <2, 2 to <3, 3 to <6, and 6 to< 11 years old, via ingestion of soil. Using the dose algorithm and the exposure factors assumptions shown above, the $\text{LADD}_{\text{POT soiling}}$ is estimated and presented in Table VIII for the various age groups. The average dose ranged from 3.1E-06 to 8.0E-06 mg/kgday. Differences in dose are a result of differences in body weight for the various age groups. As discussed previously, dose for children 6 to <11 years old may be overestimated because mouthing behavior for this group is expected to be low. Since soil ingestion data or mouthing behavior data are not available for children under 1, dose could not be estimated for this age group. However, the dose is expected to be lower than for children 1 to <3 years old because they may spend less time outdoors than older children. This example illustrates the need for more data on children's behavior, especially for children <1 year of age and older than 6 years.

Table VIII. Lifetime Average Daily Dose for Soil Ingestion Exposure (mg/kgday)

Age Group (years)	Mean LADD (mg/kgday)
1 to <2	8.0E−06
2 to <3	6.9E−06
3 to <6	5.3E−06
6 to <11	3.1E−06

In this example, splitting the age groups into the finer age categories does not yield significantly different dose estimates because the data on the soil ingestion parameter are too limited to examine age-related differences among children. The uncertainties associated with this example scenario include the following:

- the assumption that the data on soil ingestion are representative of the ingestion rates for children in those age groups;
- the uncertainty associated with the attribution of ingestion of soil versus indoor dust (this scenario does not make any assumptions regarding the attribution of soil vs. indoor dust);
- the assumption that soil ingestion rates, which were based on studies of short duration, are representative of usual intake; and
- the assumption that the concentration in the soil is representative of the areas where children spend their time.

4. DISCUSSION

As demonstrated in the two case studies, there may be instances where combining some of the standard age groups (e.g., combining the first three groups into one representing birth to <6 months) could be considered when estimating exposure or potential dose, especially if little variation might be expected. Case Study 1 showed the importance of examining the recommended age groups, especially for younger children. In addition, there may be instances where it is not necessary to address every age group listed above because the focus of a risk assessment may be on toxicity data that indicate a health effect for which only one or two of the above groups represent a critical window. Where there is a lack of exposure data for a particular age group of potential importance, the assessment should still include a rough estimate based on exposures of other age groups and consideration of how these age groups differ. In Case Study 2, the lack of data prevented the analysis of all recommended age groups. However, surrogate data on mouthing behavior were used to make qualitative statements about the differences among the various age categories. If age groups are combined or excluded, the underlying scientific rationale should be provided in the exposure assessment. It is important for exposure assessors to engage in an iterative dialogue with toxicologists and other health scientists to determine the age groups (or portions of age groups) that will be the focus of any particular assessment. Such dialogue should include the following elements.

- The basis (exposure and/or toxicological or risk) for determining which age groups should be split, combined, and/or dropped from the analysis and why.
- The criteria used to select particular age groups for assessment. These criteria may be quantitative or qualitative depending on the quantity and quality of available data. It is of paramount importance to characterize the data, how best to combine or extrapolate, and how such manipulation may change the distribution (i.e., under- or overestimate or mask outliers).
- The scientific uncertainties and potential biases introduced when combining or excluding age groups.

A major area where a standard set of early life age groups should prove useful is in the field of exposure modeling. Currently, there are several models under development for assessing aggregate and cumulative exposures and risks. These include Calendex, developed by Novigen Sciences, Inc. (http://www.exponent.com/practices/foodchemical/calendex.html), the LifeLine Model, developed under a cooperative agreement between U.S. EPA and Hampshire Research Institute,(35) the Stochastic Human Exposure and Dose Simulation Model (SHEDS) (http://www.epa.gov/heasd/emrb/emrb.htm),(36,37) under development by U.S. EPA, the Cumulative and Aggregate Risk Evaluation System (CARES) (http://cares.ilsi.org/About+Us/), originally developed under the auspices of CropLife America (CLA) and then transferred to the International Life Sciences Institute (ILSI), and the Residential Exposure Year Model (RexY) (http://www.infoscientific.com/software_main.htm), under development by Infosciences.com. Generally, these models are being developed to address the aggregate exposure/cumulative risk mandates for pesticides under the Food Quality Protection Act of 1996 (FQPA). Each of these models involves combining exposures to an individual or population of individuals across sources, pathways, and routes and presenting the exposure results at a given time or as time profiles. It is important for the exposure assessor to develop a full understanding of the model construct and sampling algorithms used by each model. Such an understanding will allow the model outputs to be interpreted in light of the recommended childhood age groups and will allow for a more complete characterization of uncertainties.

A model could randomly sample food consumption data from the 1994/1996 Continuing Survey of Food Intake by Individuals (CSFII)(23) by drawing from age bins defined by the modeler. The ages included in each bin might be selected based on statistical considerations (e.g., achieving a certain sample size within each bin) or other factors (e.g., expert judgment regarding reasonable extrapolations across ages). The sampling bins selected may not align with the childhood age groups recommended in this article. For example, daily food consumption estimates for children ages 1 to <2 years and 2 to <3 years may be drawn from a single bin representing 1 to <3 years. In this case, a food intake estimate for a child near the age of 3 years may be randomly drawn to represent the intake of a child near the age of 1 year. Such circumstances may result in inaccuracies in the exposure assessment. Additional data on daily food consumption by children using the CSFII 1998(23) survey will allow the sampling bins in this model to be refined to more closely align with the recommended childhood age groups (see recommendation in Table II).

EPA's recent *Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens*(38) has demonstrated the importance of integrating age-specific differences in exposure and toxicity when assessing risk. The complexity of this integration will depend to a large degree on the overlap versus concordance of exposure-specific and of toxicity-specific age groups. EPA's *Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens* demonstrated increased early life cancer potency for carcinogens with a mutagenic mode of action. When chemical-specific data are not available, adjustments in carcinogenic potency are made to the following age groups: 0 <2 years (10-fold increase as compared to adult potency); 2 <16 years (three-fold increase); and 16 and older. Table IX illustrates how to consider both (1) the exposure age groups defined in this article with (2) the toxicologically relevant age groups for carcinogens

Table IX. Integrating this Age Grouping Guidance with the *Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens* that Act via a Mutagenic Mode of Action

Exposure Age Groupings	Exposure Duration (years)	Potency Adjustment[a]
Birth to < 1 month	0.083	10×
1 to <3 months	0.167	10×
3 to <6 months	0.25	10×
6 to <12 months	0.5	10×
1 to <2 years	1	10×
2 to <3 years	1	3×
3 to <6 years	3	3×
6 to <11 years	5	3×
11 to <16 years	5	3×
16 to <21 years	5	1×
> 21 years (21 < 70)	49	1×

[a] Potency adjustments as described in the *Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens.*(38)

with mutagenic mode of action. The exposure age groups are listed in the first column, and the sensitive age groups are indicated by the three different shaded bands. When assessing risk, a time-weighted risk (a function of exposure and toxicity multiplied by the ratio of the relevant exposure duration to the total lifespan considered) for each relevant age group would be calculated and then summed.

If exposure only occurs for a limited number of years (for example, a family that lived near a source of exposure for a five-year period of time), it is critical to combine life stage differences in exposure and carcinogenic potency differences in life stage for the relevant time interval. Example calculations are provided in Section 6 of EPA's *Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens*.

5. CONCLUSIONS

The article describes a set of standard age groupings that can be used and, when necessary, adapted for purposes of designing monitoring studies and conducting risk assessments focused on children. This set of age groupings are based on current understanding of differences in life stage behavior, anatomy, and physiology and can serve as a starting set for consideration by exposure and risk assessors and researchers. Although dose-rate averaging over specific age groups is commonly used by exposure assessors, a consistent set of age groups will assist in improving the accuracy and consistency of children's exposure assessments. In specific situations, it is recognized that exposure factors data may not be available for many of the recommended age groupings or that a specific age group may not need to be the subject of a particular assessment so flexibility and professional judgment is essential in applying these generic age groupings. In general, the basis for deciding which age groups would be split, combined, and/or dropped from the analysis is determined by whether data are sufficient and whether lumping age groups yields different exposure estimates than maintaining the separate age groups.

There are many efforts underway within the EPA and elsewhere to address developmental issues and to characterize physical variations that occur in different life stages throughout the life span. There will always be a need to balance the added value of increased resolution against the cost of generating the necessary exposure data. The standard age groupings described here can focus future research and data collection efforts so that one can move toward a goal of conducting exposure assessments that address all significant variations in life stage.

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DISCLAIMER

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