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Exposure Factors Handbook: 2011 Edition






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

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EXPOSURE FACTORS HANDBOOK:
2011 EDITION

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U.S. Environmental Protection Agency
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FOREWORD

The U.S. Environmental Protection Agency (U.S. EPA), Office of Research and Development (ORD), National Center for Environmental Assessment's (NCEA) mission is to provide guidance and risk assessments aimed at protecting human health and the environment. To accomplish this mission, NCEA works to develop and improve the models, databases, tools, assumptions, and extrapolations used in risk assessments. NCEA established the Exposure Factors Program to develop tools and databases that improve the scientific basis of exposure and risk assessment by (1) identifying exposure factors needs in consultation with clients, and exploring ways for filling data gaps; (2) compiling existing data on exposure factors needed for assessing exposures/risks; and (3) assisting clients in the use of exposure factors data. The *Exposure Factors Handbook and* the *Child-Specific Exposure Factors Handbook,* as well as other companion documents such as *Example Exposure Scenarios,* are products of the Exposure Factors Program.

The *Exposure Factors Handbook* provides information on various physiological and behavioral factors commonly used in assessing exposure to environmental chemicals. The handbook was first published in 1989 and was updated in 1997. Since then, new data have become available. This updated edition incorporates data available since 1997 up to July 2011. It also reflects the revisions made to the *Child-Specific Exposure Factors Handbook*, which was updated and published in 2008. This edition of the handbook supersedes the information presented in the 2008 *Child-Specific Exposure Factors Handbook.* Each chapter in the 2011 edition of the *Exposure Factors Handbook* presents recommended values for the exposure factors covered in the chapter as well as a discussion of the underlying data used in developing the recommendations. These recommended values are based solely on NCEA's interpretations of the available data. In many situations, different values may be appropriate to use in consideration of policy, precedent, or other factors.

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The National Center for Environmental Assessment (NCEA), Office of Research and Development was responsible for the preparation of this handbook. Jacqueline Moya served as the Work Assignment Manager for the current updated edition, providing overall direction and technical assistance, and is a contributing author. The current draft was prepared by Westat Inc. under contract with the U.S. EPA (contract number GS-23F-8144H). Earlier drafts of this report were prepared by Versar, Inc.

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EXECUTIVE SUMMARY

Some of the steps for performing an exposure assessment are (1) identifying the source of the environmental contamination and the media that transports the contaminant; (2) determining the contaminant concentration; (3) determining the exposure scenarios, and pathways and routes of exposure; (4) determining the exposure factors related to human behaviors that define time, frequency, and duration of exposure; and (5) identifying the exposed population. Exposure factors are factors related to human behavior and characteristics that help determine an individual's exposure to an agent. This *Exposure Factors Handbook* has been prepared to provide information and recommendations on various factors used in assessing exposure to both adults and children. The purpose of the *Exposure Factors Handbook* is to (1) summarize data on human behaviors and characteristics that affect exposure to environmental contaminants, and (2) recommend values to use for these factors. This handbook provides nonchemical-specific data on the following exposure factors:

- Ingestion of water and other selected liquids (see Chapter 3),
- Non-dietary ingestion factors (see Chapter 4),
- Ingestion of soil and dust (see Chapter 5),
- Inhalation rates (see Chapter 6),
- Dermal factors (see Chapter 7),
- Body weight (see Chapter 8),
- Intake of fruits and vegetables (see Chapter 9),
- Intake of fish and shellfish (see Chapter 10),
- Intake of meat, dairy products, and fats (see Chapter 11),
- Intake of grain products (see Chapter 12),
- Intake of home-produced food (see Chapter 13),
- Total food intake (see Chapter 14),
- Human milk intake (see Chapter 15),
- Activity factors (see Chapter 16),
- Consumer products (see Chapter 17),
- Lifetime (see Chapter 18), and
- Building characteristics (see Chapter 19).

The handbook was first published in 1989 and was revised in 1997 (U.S. EPA, 1989, 1997). Recognizing that exposures among infants, toddlers, adolescents, and teenagers can vary significantly, the U.S. EPA published the *Child-Specific Exposure Factors Handbook* in 2002 (U.S. EPA, 2002) and its revision in 2008 (U.S. EPA, 2008). The 2008 revision of the *Child-Specific Exposure Factors Handbook* as well as this 2011 edition of the

Exposure Factors Handbook reflect the age categories recommended in the U.S. EPA *Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants* (U.S. EPA, 2005). This 2011 edition of the *Exposure Factors Handbook* also incorporates new factors and data provided in the 2008 *Child-Specific Exposure Factors Handbook* (and other relevant information published through July 2011. The information presented in this 2011 edition of the *Exposure Factors Handbook* supersedes the 2008 *Child-Specific Exposure Factors Handbook.*

The data presented in this handbook have been compiled from various sources, including government reports and information presented in the scientific literature. The data presented are the result of analyses by the individual study authors. However, in some cases, the U.S. EPA conducted additional analysis of published primary data to present results in a way that will be useful to exposure assessors and/or in a manner that is consistent with the recommended age groups. Studies presented in this handbook were chosen because they were seen as useful and appropriate for estimating exposure factors based on the following considerations: (1) soundness (adequacy of approach and minimal or defined bias); (2) applicability and utility (focus on the exposure factor of interest, representativeness of the population, currency of the information, and adequacy of the data collection period); (3) clarity and completeness (accessibility, reproducibility, and quality assurance); (4) variability and uncertainty (variability in the population and uncertainty in the results); and (5) evaluation and review (level of peer review and number and agreement of studies). Generally, studies were designated as “key” or “relevant” studies. Key studies were considered the most up-to-date and scientifically sound for deriving recommendations; while relevant studies provided applicable or pertinent data, but not necessarily the most important for a variety of reasons (e.g., data were outdated, limitations in study design). The recommended values for exposure factors are based on the results of key studies. The U.S. EPA also assigned confidence ratings of *low, medium, or high* to each recommended value based on the evaluation elements described above. These ratings are not intended to represent uncertainty analyses; rather, they represent the U.S. EPA’s judgment on the quality of the underlying data used to derive the recommendations.

Key recommendations from the handbook are summarized in Table ES-1. Additional recommendations and detailed supporting information for these recommendations can be found in the individual chapters of this handbook. In providing recommendations for the various exposure factors, an attempt was made to present percentile values that are consistent with the exposure estimators defined in the *Guidelines for Exposure Assessment* (U.S. EPA, 1992) (i.e., mean and upper percentile). However, this was not always possible because the data available were limited for some factors, or the authors of the study did not provide such information. As used throughout this handbook, the term “upper percentile” is intended to represent values in the upper tail (i.e., between 90^{th} and 99.9^{th} percentile) of the distribution of values for a particular exposure factor. The 95^{th} percentile was used throughout the handbook to represent the upper tail because it is the middle of the range between 90^{th} and 99^{th} percentile. Other percentiles are presented, where available, in the tables at the end of each chapter. It should be noted that users of the handbook may use the exposure metric that is most appropriate for their particular situation.

The recommendations provided in this handbook are not legally binding on any U.S. EPA program and should be interpreted as suggestions that program offices or individual exposure/risk assessors can consider and modify as needed based on their own evaluation of a given risk assessment situation. In certain cases, different values may be appropriate in consideration of policy, precedent, strategy, or other factors (e.g., more up-to-date data of better quality or more representative of the population of concern).

REFERENCES FOR THE EXECUTIVE SUMMARY

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Table ES-1. Summary of Exposure Factor Recommendations

Chapter 3	PER CAPITA INGESTION OF DRINKING WATER				CONSUMERS-ONLY INGESTION OF DRINKING WATER			
	Mean		95th Percentile		Mean		95th Percentile	
	mL/day	mL/kg-day	mL/day	mL/kg-day	mL/day	mL/kg-day	mL/day	mL/kg-day
Children								
Birth to 1 month	184	52	839[a]	232[a]	470[a]	137[a]	858[a]	238[a]
1 to <3 months	227[a]	48	896[a]	205[a]	552	119	1,053[a]	285[a]
3 to <6 months	362[a]	52	1,056	159	556	80	1,171[a]	173[a]
6 to <12 months	360	41	1,055	126	467	53	1,147	129
1 to <2 years	271	23	837	71	308	27	893	75
2 to <3 years	317	23	877	60	356	26	912	62
3 to <6 years	327	18	959	51	382	21	999	52
6 to <11 years	414	14	1,316	43	511	17	1,404	47
11 to <16 years	520	10	1,821	32	637	12	1,976	35
16 to <18 years	573	9	1,783	28	702	10	1,883	30
18 to <21 years	681	9	2,368	35	816	11	2,818	36
Adults								
>21 years	1,043	13	2,958	40	1,227	16	3,092	42
>65 years	1,046	14	2,730	40	1,288	18	2,960	43
Pregnant women	819[a]	13[a]	2,503[a]	43[a]	872[a]	14[a]	2,589[a]	43[a]
Lactating women	1,379[a]	21[a]	3,434[a]	55[a]	1,665[a]	26[a]	3,588[a]	55[a]

[a] Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993).

Chapter 3	INGESTION OF WATER WHILE SWIMMING			
	Mean		Upper Percentile	
	mL/event[a]	mL/hour	mL/event	mL/hour
Children	37	49	90[b]	120[b]
Adults	16	21	53[c]	71[c]

[a] Participants swam for 45 minutes.
[b] 97th percentile
[c] Based on maximum value.

Chapter 4	MOUTHING FREQUENCY AND DURATION							
	Hand-to-Mouth				Object-to-Mouth			
	Indoor Frequency		Outdoor Frequency		Indoor Frequency		Outdoor Frequency	
	Mean contacts/ hour	95th Percentile contacts/ hour	Mean contacts/ hour	95th Percentile contacts/hour	Mean contacts/ hour	95th Percentile contacts/ hour	Mean contacts/ hour	95th Percentile contacts/ hour
Birth to 1 month	-	-	-	-	-	-	-	-
1 to <3 months	-	-	-	-	-	-	-	-
3 to <6 months	28	65	-	-	11	32	-	-
6 to <12 months	19	52	15	47	20	38	-	-
1 to <2 years	20	63	14	42	14	34	8.8	21
2 to <3 years	13	37	5	20	9.9	24	8.1	40
3 to <6 years	15	54	9	36	10	39	8.3	30
6 to <11 years	7	21	3	12	1.1	3.2	1.9	9.1
11 to <16 years	-	-	-	-	-	-	-	-
16 to <21 years	-	-	-	-	-	-	-	-

	Object-to-Mouth Duration	
	Mean minute/hour	95th Percentile minute/hour
Birth to 1 month	-	-
1 to <3 months	-	-
3 to <6 months	11	26
6 to <12 months	9	19
1 to <2 years	7	22
2 to <3 years	10	11
3 to <6 years	-	-
6 to <11 years	-	-
11 to <16 years	-	-
16 to <21 years	-	-

\- No data.

Table ES-1. Summary of Exposure Factor Recommendations (continued)

Chapter 5 **SOIL AND DUST INGESTION**

	Soil				Dust		Soil + Dust	
	General Population Central Tendency mg/day	High End						
		General Population Upper Percentile mg/day	Soil-Pica mg/day	Geophagy mg/day	Central Tendency mg/day	General Population Upper Percentile mg/day	General Population Central Tendency mg/day	General Population Upper Percentile mg/day
6 weeks to <1 year	30	-	-	-	30	-	60	-
1 to <6 years	50	-	1,000	50,000	60	-	100	-
3 to <6 years	-	200	-	-	-	100	-	200
6 to <21 years	50	-	1,000	50,000	60	-	100	-
Adult	20	-	-	50,000	30	-	50	-

\- No data.

Chapter 6 **INHALATION**

	Long-Term Inhalation Rates	
	Mean m^3/day	95th Percentile m^3/day
Birth to 1 month	3.6	7.1
1 to <3 months	3.5	5.8
3 to <6 months	4.1	6.1
6 to <12 months	5.4	8.0
1 to <2 years	5.4	9.2
Birth to <1year	8.0	12.8
2 to <3 years	8.9	13.7
3 to <6 years	10.1	13.8
6 to <11 years	12.0	16.6
11 to <16 years	15.2	21.9
16 to <21 years	16.3	24.6
21 to <31 years	15.7	21.3
31 to <41 years	16.0	21.4
41 to <51 years	16.0	21.2
51 to <61 years	15.7	21.3
61 to <71 years	14.2	18.1
71 to <81 years	12.9	16.6
≥81 years	12.2	15.7

	Short-Term Inhalation Rates, by Activity Level									
	Sleep or Nap		Sedentary/Passive		Light Intensity		Moderate Intensity		High Intensity	
	Mean m^3/ minute	95th m^3/ minute	Mean m^3/ minute	95th m^3/ minute	Mean m^3/ minute	95th m^3/ minute	Mean m^3/ minute	95th m^3/ minute	Mean m^3/ minute	95th m^3/ minute
Birth to <1year	3.0E–03	4.6E–03	3.1E–03	4.7E–03	7.6E–03	1.1E–02	1.4E–02	2.2E–02	2.6E–02	4.1E–02
1 to <2 years	4.5E–03	6.4E–03	4.7E–03	6.5E–03	1.2E–02	1.6E–02	2.1E–02	2.9E–02	3.8E–02	5.2E–02
2 to <3 years	4.6E–03	6.4E–03	4.8E–03	6.5E–03	1.2E–02	1.6E–02	2.1E–02	2.9E–02	3.9E–02	5.3E–02
3 to <6 years	4.3E–03	5.8E–03	4.5E–03	5.8E–03	1.1E–02	1.4E–02	2.1E–02	2.7E–02	3.7E–02	4.8E–02
6 to <11 years	4.5E–03	6.3E–03	4.8E–03	6.4E–03	1.1E–02	1.5E–02	2.2E–02	2.9E–02	4.2E–02	5.9E–02
11 to <16 years	5.0E–03	7.4E–03	5.4E–03	7.5E–03	1.3E–02	1.7E–02	2.5E–02	3.4E–02	4.9E–02	7.0E–02
16 to <21 years	4.9E–03	7.1E–03	5.3E–03	7.2E–03	1.2E–02	1.6E–02	2.6E–02	3.7E–02	4.9E–02	7.3E–02
21 to <31 years	4.3E–03	6.5E–03	4.2E–03	6.5E–03	1.2E–02	1.6E–02	2.6E–02	3.8E–02	5.0E–02	7.6E–02
31 to <41 years	4.6E–03	6.6E–03	4.3E–03	6.6E–03	1.2E–02	1.6E–02	2.7E–02	3.7E–02	4.9E–02	7.2E–02
41 to <51 years	5.0E–03	7.1E–03	4.8E–03	7.0E–03	1.3E–02	1.6E–02	2.8E–02	3.9E–02	5.2E–02	7.6E–02
51 to <61 years	5.2E–03	7.5E–03	5.0E–03	7.3E–03	1.3E–02	1.7E–02	2.9E–02	4.0E–02	5.3E–02	7.8E–02
61 to <71 years	5.2E–03	7.2E–03	4.9E–03	7.3E–03	1.2E–02	1.6E–02	2.6E–02	3.4E–02	4.7E–02	6.6E–02
71 to <81 years	5.3E–03	7.2E–03	5.0E–03	7.2E–03	1.2E–02	1.5E–02	2.5E–02	3.2E–02	4.7E–02	6.5E–02
≥81 years	5.2E–03	7.0E–03	4.9E–03	7.0E–03	1.2E–02	1.5E–02	2.5E–02	3.1E–02	4.8E–02	6.8E–02

Table ES-1. Summary of Exposure Factor Recommendations (continued)

Chapter 7 **SURFACE AREA**

Total Surface Area

	Mean m^2	95th Percentile m^2
Birth to 1 month	0.29	0.34
1 to <3 months	0.33	0.38
3 to <6 months	0.38	0.44
6 to <12 months	0.45	0.51
1 to <2 years	0.53	0.61
2 to <3 years	0.61	0.70
3 to <6 years	0.76	0.95
6 to <11 years	1.08	1.48
11 to <16 years	1.59	2.06
16 to <21 years	1.84	2.33
Adult Males		
21 to <30 years	2.05	2.52
30 to <40 years	2.10	2.50
40 to <50 years	2.15	2.56
50 to <60 years	2.11	2.55
60 to <70 years	2.08	2.46
70 to <80 years	2.05	2.45
≥80 years	1.92	2.22
Adult Females		
21 to <30 years	1.81	2.25
30 to <40 years	1.85	2.31
40 to <50 years	1.88	2.36
50 to <60 years	1.89	2.38
60 to <70 years	1.88	2.34
70 to <80 years	1.77	2.13
≥80 years	1.69	1.98

Percent Surface Area of Body Parts

	Head	Trunk	Arms	Hands	Legs	Feet
	Mean Percent of Total Surface Area					
Birth to 1 month	18.2	35.7	13.7	5.3	20.6	6.5
1 to <3 months	18.2	35.7	13.7	5.3	20.6	6.5
3 to <6 months	18.2	35.7	13.7	5.3	20.6	6.5
6 to <12 months	18.2	35.7	13.7	5.3	20.6	6.5
1 to <2 years	16.5	35.5	13.0	5.7	23.1	6.3
2 to <3 years	8.4	41.0	14.4	4.7	25.3	6.3
3 to <6 years	8.0	41.2	14.0	4.9	25.7	6.4
6 to <11 years	6.1	39.6	14.0	4.7	28.8	6.8
11 to <16 years	4.6	39.6	14.3	4.5	30.4	6.6
16 to <21 years	4.1	41.2	14.6	4.5	29.5	6.1
Adult Males ≥21	6.6	40.1	15.2	5.2	33.1	6.7
Adult Females ≥21	6.2	35.4	12.8	4.8	32.3	6.6

Surface Area of Body Parts

	Head		Trunk		Arms		Hands		Legs		Feet	
	Mean m^2	95th m^2	Mean m^2	95th m^2	Mean m^2	95th m^2	Mean m^2	95th m^2	Mean m^2	95th m^2	Mean m^2	95th m^2
Birth to 1 month	0.053	0.062	0.104	0.121	0.040	0.047	0.015	0.018	0.060	0.070	0.019	0.022
1 to <3 months	0.060	0.069	0.118	0.136	0.045	0.052	0.017	0.020	0.068	0.078	0.021	0.025
3 to <6 months	0.069	0.080	0.136	0.157	0.052	0.060	0.020	0.023	0.078	0.091	0.025	0.029
6 to <12 months	0.082	0.093	0.161	0.182	0.062	0.070	0.024	0.027	0.093	0.105	0.029	0.033
1 to <2 years	0.087	0.101	0.188	0.217	0.069	0.079	0.030	0.035	0.122	0.141	0.033	0.038
2 to <3 years	0.051	0.059	0.250	0.287	0.088	0.101	0.028	0.033	0.154	0.177	0.038	0.044
3 to <6 years	0.060	0.076	0.313	0.391	0.106	0.133	0.037	0.046	0.195	0.244	0.049	0.061
6 to <11 years	0.066	0.090	0.428	0.586	0.151	0.207	0.051	0.070	0.311	0.426	0.073	0.100
11 to <16 years	0.073	0.095	0.630	0.816	0.227	0.295	0.072	0.093	0.483	0.626	0.105	0.136
16 to <21 years	0.076	0.096	0.759	0.961	0.269	0.340	0.083	0.105	0.543	0.687	0.112	0.142
Adult Males ≥21	0.136	0.154	0.827	1.10	0.314	0.399	0.107	0.131	0.682	0.847	0.137	0.161
Adult Females ≥21	0.114	0.121	0.654	0.850	0.237	0.266	0.089	0.106	0.598	0.764	0.122	0.146

Table ES-1. Summary of Exposure Factor Recommendations (continued)

Chapter 7 — MEAN SOLID ADEHERENCE TO SKIN (mg/cm^2)

	Face	Arms	Hands	Legs	Feet
Children					
Residential (indoors)[a]	-	0.0041	0.0011	0.0035	0.010
Daycare (indoors and outdoors)[b]	-	0.024	0.099	0.020	0.071
Outdoor sports[c]	0.012	0.011	0.11	0.031	-
Indoor sports[d]	-	0.0019	0.0063	0.0020	0.0022
Activities with soil[e]	0.054	0.046	0.17	0.051	0.20
Playing in mud[f]	-	11	47	23	15
Playing in sediment[g]	0.040	0.17	0.49	0.70	21
Adults					
Outdoor sports[i]	0.0314	0.0872	0.1336	0.1223	-
Activities with soil[h]	0.0240	0.0379	0.1595	0.0189	0.1393
Construction activities[j]	0.0982	0.1859	0.2763	0.0660	-
Clamming[k]	0.02	0.12	0.88	0.16	0.58

[a] Based on weighted average of geometric mean soil loadings for 2 groups of children (ages 3 to 13 years; *N* = 10) playing indoors.

[b] Based on weighted average of geometric mean soil loadings for 4 groups of daycare children (ages 1 to 6.5 years; *N* = 21) playing both indoors and outdoors.

[c] Based on geometric mean soil loadings of 8 children (ages 13 to 15 years) playing soccer.

[d] Based on geometric mean soil loadings of 6 children (ages ≥8 years) and 1 adult engaging in Tae Kwon Do.

[e] Based on weighted average of geometric mean soil loadings for gardeners and archeologists (ages 16 to 35 years).

[f] Based on weighted average of geometric mean soil loadings of 2 groups of children (age 9 to 14 years; *N* = 12) playing in mud.

[g] Based on geometric mean soil loadings of 9 children (ages 7 to 12 years) playing in tidal flats.

[h] Based on weighted average of geometric mean soil loadings of 3 groups of adults(ages 23 to 33 years) playing rugby and 2 groups of adults (ages 24 to 34) playing soccer.

[i] Based on weighted average of geometric mean soil loadings for 69 gardeners, farmers, groundskeepers, landscapers, and archeologists (ages 16 to 64 years) for faces, arms and hands; 65 gardeners, farmers, groundskeepers, and archeologists (ages 16 to 64 years) for legs; and 36 gardeners, groundskeepers, and archeologists (ages 16 to 62) for feet.

[j] Based on weighted average of geometric mean soil loadings for 27 construction workers, utility workers and equipment operators (ages 21 to 54) for faces, arms, and hands; and based on geometric mean soil loadings for 8 construction workers (ages 21 to 30 years) for legs.

[k] Based on geometric mean soil loadings of 18 adults (ages 33 to 63 years) clamming in tidal flats.

\- No data.

Chapter 8 — BODY WEIGHT

	Mean Kg
Birth to 1 month	4.8
1 to <3 months	5.9
3 to <6 months	7.4
6 to <12 months	9.2
1 to <2 years	11.4
2 to <3 years	13.8
3 to <6 years	18.6
6 to <11 years	31.8
11 to <16 years	56.8
16 to <21 years	71.6
Adults	80.0

Table ES-1. Summary of Exposure Factor Recommendations (continued)

Chapter 9 **FRUIT AND VEGETABLE INTAKE**

	Per Capita		Consumers-Only	
	Mean g/kg-day	95th Percentile g/kg-day	Mean g/kg-day	95th Percentile g/kg-day
Total Fruits				
Birth to 1 year	6.2	23.0[a]	10.1	25.8[a]
1 to <2 years	7.8	21.3[a]	8.1	21.4[a]
2 to <3 years	7.8	21.3[a]	8.1	21.4[a]
3 to <6 years	4.6	14.9	4.7	15.1
6 to <11 years	2.3	8.7	2.5	9.2
11 to <16 years	0.9	3.5	1.1	3.8
16 to <21 years	0.9	3.5	1.1	3.8
21 to <50 years	0.9	3.7	1.1	3.8
≥50 years	1.4	4.4	1.5	4.6
Total Vegetables				
Birth to 1 year	5.0	16.2[a]	6.8	18.1[a]
1 to <2 years	6.7	15.6[a]	6.7	15.6[a]
2 to <3 years	6.7	15.6[a]	6.7	15.6[a]
3 to <6 years	5.4	13.4	5.4	13.4
6 to <11 years	3.7	10.4	3.7	10.4
11 to <16 years	2.3	5.5	2.3	5.5
16 to <21 years	2.3	5.5	2.3	5.5
21 to <50 years	2.5	5.9	2.5	5.9
≥50 years	2.6	6.1	2.6	6.1

[a] Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993).

Chapter 10 **FISH INTAKE**

	Per Capita		Consumers-Only	
	Mean g/kg-day	95th Percentile g/kg-day	Mean g/kg-day	95th Percentile g/kg-day
General Population—Finfish				
All	0.16	1.1	0.73	2.2
Birth to 1 year	0.03	0.0[a]	1.3	2.9[a]
1 to <2 years	0.22	1.2[a]	1.6	4.9[a]
2 to <3 years	0.22	1.2[a]	1.6	4.9[a]
3 to <6 years	0.19	1.4	1.3	3.6[a]
6 to <11 years	0.16	1.1	1.1	2.9[a]
11 to <16 years	0.10	0.7	0.66	1.7
16 to <21 years	0.10	0.7	0.66	1.7
21 to <50 years	0.15	1.0	0.65	2.1
Females 13 to 49 years	0.14	0.9	0.62	1.8
≥50 years	0.20	1.2	0.68	2.0
General Population—Shellfish				
All	0.06	0.4	0.57	1.9
Birth to 1 year	0.00	0.0[a]	0.42	2.3[a]
1 to <2 years	0.04	0.0[a]	0.94	3.5[a]
2 to <3 years	0.04	0.0[a]	0.94	3.5[a]
3 to <6 years	0.05	0.0	1.0	2.9[a]
6 to <11 years	0.05	0.2	0.72	2.0[a]
11 to <16 years	0.03	0.0	0.61	1.9
16 to <21years	0.03	0.0	0.61	1.9
21 to <50 years	0.08	0.5	0.63	2.2
Females 13 to 49 years	0.06	0.3	0.53	1.8
≥50 years	0.05	0.4	0.41	1.2

Table ES-1. Summary of Exposure Factor Recommendations (continued)				
General Population—Total Finfish and Shellfish				
All	0.22	1.3	0.78	2.4
Birth to 1 year	0.04	0.0[a]	1.2	2.9[a]
1 to <2 years	0.26	1.6[a]	1.5	5.9[a]
2 to <3 years	0.26	1.6[a]	1.5	5.9[a]
3 to <6 years	0.24	1.6[a]	1.3	3.6[a]
6 to <11 years	0.21	1.4	0.99	2.7[a]
11 to <16 years	0.13	1.0	0.69	1.8
16 to <21 years	0.13	1.0	0.69	1.8
21 to <50 years	0.23	1.3	0.76	2.5
Females 13 to 49 years	0.19	1.2	0.68	1.9
≥50 years	0.25	1.4	0.71	2.1
[a] Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993).				
Recreational Population—Marine Fish—Atlantic				
	Mean g/day	95th Percentile g/day		
3 to <6 years	2.5	8.8		
6 to <11 years	2.5	8.6		
11 to <16 years	3.4	13		
16 to <18 years	2.8	6.6		
>18 years	5.6	18		
Recreational Population—Marine Fish—Gulf				
3 to <6 years	3.2	13		
6 to <11 years	3.3	12		
11 to <16 years	4.4	18		
16 to <18 years	3.5	9.5		
>18 years	7.2	26		
Recreational Population—Marine Fish—Pacific				
3 to <6 years	0.9	3.3		
6 to <11 years	0.9	3.2		
11 to <16 years	1.2	4.8		
16 to <18 years	1.0	2.5		
>18 years	2.0	6.8		
Recreational Population—Freshwater Fish—See Chapter 10				
Native American Population—See Chapter 10				
Other Populations—See Chapter 10				
Chapter 11	**MEATS, DAIRY PRODUCTS, AND FAT INTAKE**			
	Per Capita		Consumers-Only	
	Mean g/kg-day	95th Percentile g/kg-day	Mean g/kg-day	95th Percentile g/kg-day
Total Meats				
Birth to 1 year	1.2	5.4[a]	2.7	8.1[a]
1 to <2 years	4.0	10.0[a]	4.1	10.1[a]
2 to <3 years	4.0	10.0[a]	4.1	10.1[a]
3 to <6 years	3.9	8.5	3.9	8.6
6 to <11 years	2.8	6.4	2.8	6.4
11 to <16 years	2.0	4.7	2.0	4.7
16 to <21 years	2.0	4.7	2.0	4.7
21 to <50 years	1.8	4.1	1.8	4.1
≥50 years	1.4	3.1	1.4	3.1
Total Dairy Products				
Birth to 1 year	10.1	43.2[a]	11.7	44.7[a]
1 to <2 years	43.2	94.7[a]	43.2	94.7[a]
2 to <3 years	43.2	94.7[a]	43.2	94.7[a]
3 to <6 years	24.0	51.1	24.0	51.1
6 to <11 years	12.9	31.8	12.9	31.8
11 to <16 years	5.5	16.4	5.5	16.4
16 to <21 years	5.5	16.4	5.5	16.4
21 to <50 years	3.5	10.3	3.5	10.3
≥50 years	3.3	9.6	3.3	9.6

Table ES-1. Summary of Exposure Factor Recommendations (continued)

	Total Fats			
Birth to 1 month	5.2	16	7.8	16
1 to <3 months	4.5	12	6.0	12
3 to <6 months	4.1	8.2	4.4	8.3
6 to <12 months	3.7	7.0	3.7	7.0
1 to <2 years	4.0	7.1	4.0	7.1
2 to <3 years	3.6	6.4	3.6	6.4
3 to <6 years	3.4	5.8	3.4	5.8
6 to <11 years	2.6	4.2	2.6	4.2
11 to <16 years	1.6	3.0	1.6	3.0
16 to <21 years	1.3	2.7	1.3	2.7
21 to <31 years	1.2	2.3	1.2	2.3
31 to <41 years	1.1	2.1	1.1	2.1
41 to <51 years	1.0	1.9	1.0	1.9
51 to <61 years	0.9	1.7	0.9	1.7
61 to <71 years	0.9	1.7	0.9	1.7
71 to <81 years	0.8	1.5	0.8	1.5
≥81 years	0.9	1.5	0.9	1.5

[a] Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993).

Chapter 12 — GRAINS INTAKE

	Per Capita		Consumers-Only	
	Mean g/kg-day	95th Percentile g/kg-day	Mean g/kg-day	95th Percentile g/kg-day
Birth to 1 year	3.1	9.5[a]	4.1	10.3[a]
1 to <2 years	6.4	12.4[a]	6.4	12.4[a]
2 to <3 years	6.4	12.4[a]	6.4	12.4[a]
3 to <6 years	6.2	11.1	6.2	11.1
6 to <11 years	4.4	8.2	4.4	8.2
11 to <16 years	2.4	5.0	2.4	5.0
16 to <21 years	2.4	5.0	2.4	5.0
21 to <50 years	2.2	4.6	2.2	4.6
≥50 years	1.7	3.5	1.7	3.5

[a] Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993).

Chapter 13 — HOME-PRODUCED FOOD INTAKE

	Mean g/kg-day	95th Percentile g/kg-day
	Consumer-Only Home-Produced Fruits, Unadjusted[a]	
1 to 2 years	8.7	60.6
3 to 5 years	4.1	8.9
6 to 11 years	3.6	15.8
12 to 19 years	1.9	8.3
20 to 39 years	2.0	6.8
40 to 69 years	2.7	13.0
≥70 years	2.3	8.7
	Consumer-Only Home-Produced Vegetables, Unadjusted[a]	
1 to 2 years	5.2	19.6
3 to 5 years	2.5	7.7
6 to 11 years	2.0	6.2
12 to 19 years	1.5	6.0
20 to 39 years	1.5	4.9
40 to 69 years	2.1	6.9
≥70 years	2.5	8.2
	Consumer-Only Home-Produced Meats, Unadjusted[a]	
1 to 2 years	3.7	10.0
3 to 5 years	3.6	9.1
6 to 11 years	3.7	14.0
12 to 19 years	1.7	4.3
20 to 39 years	1.8	6.2
40 to 69 years	1.7	5.2
≥70 years	1.4	3.5

Table ES-1. Summary of Exposure Factor Recommendations (continued)

	Consumer-Only Home-Caught Fish, Unadjusted[a]			
1 to 2 years	-		-	
3 to 5 years	-		-	
6 to 11 years	2.8		7.1	
12 to 19 years	1.5		4.7	
20 to 39 years	1.9		4.5	
40 to 69 years	1.8		4.4	
≥70 years	1.2		3.7	
	Per Capita for Populations that Garden or (Farm)			
	Home-Produced Fruits[b]		Home-Produced Vegetables[b]	
	Mean g/kg-day	95th Percentile g/kg-day	Mean g/kg-day	95th Percentile g/kg-day
1 to <2 years	1.0 (1.4)	4.8 (9.1)	1.3 (2.7)	7.1 (14)
2 to <3 years	1.0 (1.4)	4.8 (9.1)	1.3 (2.7)	7.1 (14)
3 to <6 years	0.78 (1.0)	3.6 (6.8)	1.1 (2.3)	6.1 (12)
6 to <11 years	0.40 (0.52)	1.9 (3.5)	0.80 (1.6)	4.2 (8.1)
11 to <16 years	0.13 (0.17)	0.62 (1.2)	0.56 (1.1)	3.0 (5.7)
16 to <21 years	0.13 (0.17)	0.62 (1.2)	0.56 (1.1)	3.0 (5.7)
21 to <50 years	0.15 (0.20)	0.70 (1.3)	0.56 (1.1)	3.0 (5.7)
50+ years	0.24 (0.31)	1.1 (2.1)	0.60 (1.2)	3.2 (6.1)
	Per Capita for Populations that Farm or (Raise Animals)			
	Home-Produced Meats[b]		Home-Produced Dairy	
	Mean g/kg-day	95th Percentile g/kg-day	Mean g/kg-day	95th Percentile g/kg-day
1 to <2 years	1.4 (1.4)	5.8 (6.0)	11 (13)	76 (92)
2 to <3 years	1.4 (1.4)	5.8 (6.0)	11 (13)	76 (92)
3 to <6 years	1.4 (1.4)	5.8 (6.0)	6.7 (8.3)	48 (58)
6 to <11 years	1.0 (1.0)	4.1 (4.2)	3.9 (4.8)	28 (34)
11 to <16 years	0.71 (0.73)	3.0 (3.1)	1.6 (2.0)	12 (14)
16 to <21 years	0.71 (0.73)	3.0 (3.1)	1.6 (2.0)	12 (14)
21 to <50 years	0.65 (0.66)	2.7 (2.8)	0.95 (1.2)	6.9 (8.3)
50+ years	0.51 (0.52)	2.1 (2.2)	0.92 (1.1)	6.7 (8.0)

a Not adjusted to account for preparation and post cooking losses.
b Adjusted for preparation and post cooking losses.
\- No data.

Chapter 14 TOTAL PER CAPITA FOOD INTAKE

	Mean g/kg-day	95th Percentile g/kg-day
Birth to 1 year	91	208[a]
1 to <3 years	113	185[a]
3 to <6 years	79	137
6 to <11 years	47	92
11 to <16 years	28	56
16 to <21 years	28	56
21 to <50 years	29	63
≥50 years	29	59

a Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993).

Chapter 15 HUMAN MILK AND LIPID INTAKE

	Mean		Upper Percentile	
	mL/day	mL/kg-day	mL/day	mL/kg-day
	Human Milk Intake			
Birth to 1 month	510	150	950	220
1 to <3 months	690	140	980	190
3 to <6 months	770	110	1,000	150
6 to <12 months	620	83	1,000	130
	Lipid Intake			
Birth to 1 month	20	6.0	38	8.7
1 to <3 months	27	5.5	40	8.0
3 to <6 months	30	4.2	42	6.1
6 to <12 months	25	3.3	42	5.2

Table ES-1. Summary of Exposure Factor Recommendations (continued)

Chapter 16 — **ACTIVITY FACTORS**

	Time Indoors (total) minutes/day		Time Outdoors (total) minutes/day		Time Indoors (at residence) minutes/day	
	Mean	95th Percentile	Mean	95th Percentile	Mean	95th Percentile
Birth to <1 month	1,440	-	0	-	-	-
1 to <3 months	1,432	-	8	-	-	-
3 to <6 months	1,414	-	26	-	-	-
6 to <12 months	1,301	-	139	-	-	-
Birth to <1 year	-	-	-	-	1,108	1,440
1 to <2 years	1,353	-	36	-	1,065	1,440
2 to <3 years	1,316	-	76	-	979	1,296
3 to <6 years	1,278	-	107	-	957	1,355
6 to <11 years	1,244	-	132	-	893	1,275
11 to <16 years	1,260	-	100	-	889	1,315
16 to <21 years	1,248	-	102	-	833	1,288
18 to <64 years	1,159	-	281	-	948	1,428
>64 years	1,142	-	298	-	1,175	1,440
	Showering minutes/day		**Bathing minutes/day**		**Bathing/Showering minutes/day**	
	Mean	95th Percentile	Mean	95th Percentile	Mean	95th Percentile
Birth to <1year	15	-	19	30	-	-
1 to <2 years	20	-	23	32	-	-
2 to <3 years	22	44	23	45	-	-
3 to <6 years	17	34	24	60	-	-
6 to <11 years	18	41	24	46	-	-
11 to <16 years	18	40	25	43	-	-
16 to <21 years	20	45	33	60	-	-
18 to <64 years	-	-	-	-	17	-
>64 years	-	-	-	-	17	-
	Playing on Sand/Gravel minutes/day		**Playing on Grass minutes/day**		**Playing on Dirt minutes/day**	
	Mean	95th Percentile	Mean	95th Percentile	Mean	95th Percentile
Birth to <1 year	18	-	52	-	33	-
1 to <2 years	43	121	68	121	56	121
2 to <3 years	53	121	62	121	47	121
3 to <6 years	60	121	79	121	63	121
6 to <11 years	67	121	73	121	63	121
11 to <16 years	67	121	75	121	49	120
16 to <21 years	83	-	60	-	30	-
18 to <64 years	0 (median)	121	60 (median)	121	0 (median)	120
>64 years	0 (median)	-	121 (median)	-	0 (median)	-

	Swimming minutes/month	
	Mean	95th Percentile
Birth to <1 year	96	-
1 to <2 years	105	-
2 to <3 years	116	181
3 to <6 years	137	181
6 to <11 years	151	181
11 to <16 years	139	181
16 to <21 years	145	181
18 to <64 years	45(median)	181
>64 years	40(median)	181

Table ES-1. Summary of Exposure Factor Recommendations (continued)

Occupational Mobility

	Median Tenure (years) Men	Median Tenure (years) Women
All ages, ≥16 years	7.9	5.4
16 to 24 years	2.0	1.9
25 to 29 years	4.6	4.1
30 to 34 years	7.6	6.0
35 to 39 years	10.4	7.0
40 to 44 years	13.8	8.0
45 to 49 years	17.5	10.0
50 to 54 years	20.0	10.8
55 to 59 years	21.9	12.4
60 to 64 years	23.9	14.5
65 to 69 years	26.9	15.6
≥70 years	30.5	18.8

Population Mobility

	Residential Occupancy Period (years)		Current Residence Time (years)	
	Mean	95th Percentile	Mean	95th Percentile
All	12	33	13	46

\- No data.

Chapter 17 **CONSUMER PRODUCTS - See Chapter 17**

Chapter 18 **LIFE EXPECTANCY**

	Years
Total	78
Males	75
Females	80

Chapter 19 **BUILDING CHARACTERISTICS**

Residential Buildings

	Mean	10th Percentile
Volume of Residence (m^3)	492	154
Air Exchange Rate (air changes/hour)	0.45	0.18

Non-Residential Buildings

	Mean (Standard Deviation)	10th Percentile
Volume of Non-residential Buildings (m^3)		408
Vacant	4,789	510
Office	5,036	2,039
Laboratory	24,681	1,019
Non-refrigerated warehouse	9,298	476
Food sales	1,889	816
Public order and safety	5,253	680
Outpatient healthcare	3,537	1,133
Refrigerated warehouse	19,716	612
Religious worship	3,443	595
Public assembly	4,839	527
Education	8,694	442
Food service	1,889	17,330
Inpatient healthcare	82,034	1,546
Nursing	15,522	527
Lodging	11,559	1,359
Strip shopping mall	7,891	35,679
Enclosed mall	287,978	510
Retail other than mall	3,310	459
Service	2,213	425
Other	5,236	527
All Buildings	5,575	
Air Exchange Rate (air changes/hour)	1.5 (0.87) Range 0.3–4.1	0.60

ACRONYMS AND ABBREVIATIONS

AAP	=	American Academy of Pediatrics
ACH	=	Air Changes per Hour
ADAFs	=	Age Dependent Adjustment Factors
ADD	=	Average Daily Dose
AF	=	Adherence Factor
AHS	=	American Housing Survey
AIR	=	Acid Insoluble Residue
API	=	Asian and Pacific Islander
ASHRAE	=	American Society of Heating, Refrigeration, and Air Conditioning Engineers
ASTM	=	American Society for Testing and Materials
ARS	=	Agricultural Research Service
ASCII	=	American Standard Code for Information Interchange
ATD	=	Arizona Test Dust
ATSDR	=	Agency for Toxic Substances and Disease Registry
ATUS	=	American Time Use Survey
BI	=	Bootstrap Interval
BMD	=	Benchmark Dose
BMI	=	Body Mass Index
BMR	=	Basal Metabolic Rate
BTM	=	Best Tracer Method
BW	=	Body Weight
C	=	Concentration
CATI	=	Computer-Assisted Telephone Interviewing
CDC	=	Centers for Disease Control and Prevention
CDFA	=	California Department of Food and Drugs
CDS	=	Child Development Supplement
CHAD	=	Consolidated Human Activity Database
CI	=	Confidence Interval
cm^2	=	Square Centimeter
cm^3	=	Cubic Centimeter
CNRC	=	Children’s Nutrition Research Center
CRITFC	=	Columbia River Inter-Tribal Fish Commission
CSFII	=	Continuing Survey of Food Intake by Individuals
CT	=	Central Tendency
CTFA	=	Cosmetic, Toiletry, and Fragrance Association
CV	=	Coefficient of Variation
DAF	=	Dosimetry Adjustment Factor
DARLING	=	Davis Area Research on Lactation, Infant Nutrition and Growth
DHHS	=	Department of Health and Human Services
DIR	=	Daily Inhalation Rate
DIY	=	Do-It-Yourself
DK	=	Respondent Replied “Don’t Know”
DLW	=	Doubly Labeled Water
DOE	=	Department of Energy
DONALD	=	Dortmund Nutritional and Anthropometric Longitudinally Designed
E or EE	=	Energy Expenditure
EBF	=	Exclusively Breastfed
ECG	=	Energy Cost of Growth
ED	=	Exposure Duration

ACRONYMS AND ABBREVIATIONS (continued)

EFAST	=	Exposure and Fate Assessment Screening Tool
EI	=	Energy Intake
EPA	=	Environmental Protection Agency
ERV	=	Energy Recovery Ventilator
EVR	=	Equivalent Ventilation Rate
F	=	Fahrenheit
f_B	=	Breathing Frequency
FCID	=	Food Commodity Intake Database
FITS	=	Feeding Infant and Toddler Study
F/S	=	Food/Soil
g	=	Gram
GAF	=	General Assessment Factor
GM	=	Geometric Mean
GSD	=	Geometric Standard Deviation
H	=	Oxygen Uptake Factor
HEC	=	Human Equivalent Exposure Concentrations
HR	=	Heart Rate
HRV	=	Heat Recovery Ventilator
USHUD	=	United States Department of Housing and Urban Development
I	=	Tabulated Intake Rate
I_A	=	Adjusted Intake Rate
I-BEAM	=	Indoor Air Quality Building and Assessment Model
ICRP	=	International Commission on Radiological Protection
IEUBK	=	Integrated Exposure and Uptake Biokinetic Model
IFS	=	Iowa Fluoride Study
IOM	=	Institute of Medicine
IPCS	=	International Programme on Chemical Safety
IR	=	Intake Rate/Inhalation Rate
IRIS	=	Integrated Risk Information System
IUR	=	Inhalation Unit Risk
Kcal	=	Kilocalories
KJ	=	Kilo Joules
K-S	=	Kolmogorov-Smirnov
kg	=	Kilogram
L	=	Liter
L_1	=	Cooking or Preparation Loss
L_2	=	Post-cooking Loss
LADD	=	Lifetime Average Daily Dose
LCL	=	Lower Confidence Limit
LTM	=	Limiting Tracer Method
m^2	=	Square Meter
m^3	=	Cubic Meter
MCCEM	=	Multi-Chamber Concentration and Exposure Model
MEC	=	Mobile Examination Center
mg	=	Milligram
MJ	=	Mega Joules
mL	=	Milliliter
METS	=	Metabolic Equivalents of Work
MOA	=	Mode of Action
MSA	=	Metropolitan Statistical Area
MVPA	=	Moderate-to-Vigorous Physical Activity
N	=	Number of Subjects or Respondents

ACRONYMS AND ABBREVIATIONS (continued)

N_c	=	Weighted Number of Individuals Consuming Homegrown Food Item
N_T	=	Weighted Total Number of Individuals Surveyed
NAS	=	National Academy of Sciences
NCEA	=	National Center for Environmental Assessment
NCHS	=	National Center for Health Statistics
NERL	=	National Exposure Research Laboratory
NFCS	=	Nationwide Food Consumption Survey
NHANES	=	National Health and Nutrition Examination Survey
NHAPS	=	National Human Activity Pattern Survey
NHES	=	National Health Examination Survey
NIS	=	National Immunization Survey
NLO	=	Non-Linear Optimization
NMFS	=	National Marine Fisheries Service
NOAEL	=	No-Observed-Adverse-Effect-Level
NOPES	=	Non-Occupational Pesticide Exposure Study
NR	=	Not Reported
NRC	=	National Research Council
NS	=	No Statistical Difference
OPP	=	Office of Pesticide Programs
ORD	=	Office of Research and Development
PBPK	=	Physiologically-Based Pharmacokinetic
PC	=	Percent Consuming
PDIR	=	Physiological Daily Inhalation Rate
PFT	=	Perfluorocarbon Tracer
PSID	=	Panel Study of Income Dynamics
PTEAM	=	Particle Total Exposure Assessment Methodology
RAGS	=	Risk Assessment Guidance for Superfund
RDD	=	Random Digit Dial
RECS	=	Residential Energy Conservation Survey
RfD	=	Reference Dose
RfC	=	Reference Concentration
ROP	=	Residential Occupancy Period
RTF	=	Ready to Feed
SA	=	Surface Area
SA/BW	=	Surface Area to Body Weight Ratio
SAS	=	Statistical Analysis Software
SCS	=	Soil Contact Survey
SD	=	Standard Deviation
SDA	=	Soaps and Detergent Association
SE	=	Standard Error
SEM	=	Standard Error of the Mean
SES	=	Socioeconomic Status
SHEDS	=	Stochastic Human Exposure and Dose Simulation Model
SMBRP	=	Santa Monica Bay Restoration Project
SMRB	=	Simmons Market Research Bureau
SOCAL	=	Southern California
SPS	=	Statistical Processing System
t	=	Exposure Time
TDEE	=	Total Daily Energy Expenditure
TRF	=	Tuna Research Foundation

ACRONYMS AND ABBREVIATIONS (continued)

UCL	=	Upper Confidence Limit
USDA	=	United States Department of Agriculture
USDL	=	United States Department of Labor
VE	=	Volume of Air Breathed per Day
VO_2	=	Oxygen Consumption Rate
VOC	=	Volatile Organic Compounds
VQ	=	Ventilatory Equivalent
VR	=	Ventilation Rate
VT	=	Tidal Volume
WHO	=	World Health Organization
WIC	=	USDA's Women, Infants, and Children Program

1. INTRODUCTION

1.1. BACKGROUND AND PURPOSE

Some of the steps for performing an exposure assessment are (1) identifying the source of the environmental contamination and the media that transports the contaminant; (2) determining the contaminant concentration; (3) determining the exposure scenarios, and pathways and routes of exposure; (4) determining the exposure factors related to human behaviors that define time, frequency, and duration of exposure; and (5) identifying the exposed population. Exposure factors are factors related to human behavior and characteristics that help determine an individual's exposure to an agent. The National Academy of Sciences (NAS) report on *Risk Assessment in the Federal Government: Managing the Process* and subsequent publication of the U.S. Environmental Protection Agency's (EPA) exposure guidelines in 1986 identified the need for summarizing exposure factors data necessary for characterizing some of the steps outlined above (U.S. EPA, 1987a; NRC, 1983). Around the same time, the U.S. EPA published a report entitled *Development of Statistical Distributions or Ranges of Standard Factors Used in Exposure Assessment* to support the 1986 exposure guidelines and to promote consistency in U.S. EPA's exposure assessment activities (U.S. EPA, 1985). The exposure assessment field continued to evolve and so did the need for more comprehensive data on exposure factors. The *Exposure Factors Handbook* was first published in 1989 and updated in 1997 in response to this need (U.S. EPA, 1997a, 1989a). This current edition is the update of the 1997 handbook (U.S. EPA, 1997a), and it incorporates data from the *Child-Specific Exposure Factors Handbook* (U.S. EPA, 2008a) that was published in September 2008. The information presented in this handbook supersedes the *Child-Specific Exposure Factors Handbook* published in 2008 (U.S. EPA, 2008a).

> Exposure factors are factors related to human behavior and characteristics that help determine an individual's exposure to an agent.

> Purpose:
> (1) summarize data on human behavioral and physiological characteristics
> (2) provide exposure/risk assessors with recommended values for these factors

The purpose of the *Exposure Factors Handbook* is to (1) summarize data on human behavioral and physiological characteristics that affect exposure to environmental contaminants, and (2) provide exposure/risk assessors with recommended values for these factors that can be used to assess exposure among both adults and children.

1.2. INTENDED AUDIENCE

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

1.3. SCOPE

This handbook incorporates the changes in risk assessment practices that were first presented in the U.S. EPA's Cancer Guidelines, regarding the need to consider life stages rather than subpopulations (U.S. EPA, 2005c, e). A life stage "refers to a distinguishable time frame in an individual's life characterized by unique and relatively stable behavioral and/or physiological characteristics that are associated with development and growth" (U.S. EPA, 2005b). The handbook emphasizes a major recommendation in U.S. EPA's *Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens* (U.S. EPA, 2005e) to sum exposures and risks across life stages rather than relying on the use of a lifetime average adult exposure to calculate risk. This handbook also uses updated information to incorporate any new exposure factors data/research that have become available since it was last revised in 1997 and is consistent with the U.S. EPA's new set of standardized childhood age groups (U.S. EPA, 2005b), which are recommended for use in exposure assessments. Available data through July 2011 are included in the handbook.

The recommendations presented in this handbook are not legally binding on any U.S. EPA program and should be interpreted as suggestions that program offices or individual exposure assessors can consider and modify as needed. The recommendations provided in this handbook do not supersede standards or guidance established by U.S. EPA program offices, states, or other risk assessment organizations outside the Agency (e.g., World Health Organization, National Research Council). Many of these factors are best quantified on a site- or situation-specific basis. The decision as to whether to use site-specific or national values for an assessment may depend on the quality of the competing data sets as well as on the purpose of the specific assessment. The handbook has strived to include full discussions of the issues that assessors should consider in deciding how to use these data and recommendations.

This document does not include chemical-specific data or information on physiological parameters that may be needed for exposure assessments involving physiologically based pharmacokinetic (PBPK) modeling. Information on the application of PBPK models and supporting data are found in U.S. EPA (2006a) and Lipscomb (2006).

1.4. UPDATES TO PREVIOUS VERSIONS OF THE HANDBOOK

All chapters have been revised to include published literature up to July 2011. Some of the main revisions are highlighted below:

- Added food and water intake data obtained from the National Health and Nutrition Examination Survey (NHANES) 2003–2006;
- Added fat intake data and total food intake data;
- Added new chapter on non-dietary factors;
- Updated soil ingestion rates for children and adults;
- Updated data on dermal exposure and added information on other factors such as film thickness of liquids to skin, transfer of residue, and skin thickness;
- Updated fish intake rates for the general population using data obtained from NHANES 2003–2006;
- Updated body-weight data with National Health and Nutrition Examination Survey 1999–2006;
- Added body-weight data for pregnant/lactating women and fetal weight;
- Updated children's factors with new recommended age groupings (U.S. EPA, 2005b);
- Updated life expectancy data with U.S. Census Bureau data 2006;
- Updated data on human milk ingestion and prevalence of breast-feeding; and
- Expanded residential characteristics chapter to include data from commercial buildings.

1.5. SELECTION OF STUDIES FOR THE HANDBOOK AND DATA PRESENTATION

Many scientific studies were reviewed for possible inclusion in this handbook. Although systematic literature searches were initially conducted for every chapter, much of the literature was identified through supplementary targeted searches and from personal communications with researchers in the various fields. Information in this handbook has been summarized from studies documented in the scientific literature and other publicly available sources. As such, this handbook is a compilation of data from a variety of different sources. Most of the data presented in this handbook are derived from studies that target (1) the general population (e.g., Center for Disease Control and Prevention [CDC] NHANES) or (2) a sample population from a specific area or group (e.g., fish consumption among Native American children). With very few exceptions, the data presented are the analyses of the individual study authors. Since the studies included in this handbook varied in terms of their objectives, design, scope, presentation of results, etc., the level of detail, statistics, and terminology may vary from study to study and from factor to factor. For example, some authors used geometric means to present their results, while others used arithmetic means or distributions. Authors have sometimes used different terms to describe the same racial/ethnic populations. Within the constraint of presenting the original material as accurately as possible, the U.S. EPA has made an effort to present discussions and results in a consistent manner and using consistent terminology. The strengths and limitations of each study are discussed to provide the reader with a better understanding of the uncertainties associated with the values derived from the study.

If it is necessary to characterize a population that is not directly covered by the data in this handbook, the risk or exposure assessor may need to evaluate whether these data may be used as suitable substitutes for the population of interest or whether there is a need to seek additional population-specific data. If information is needed for identifying and enumerating populations who may be at risk for greater contaminant exposures or who exhibit a heightened sensitivity to particular chemicals, refer to *Socio-demographic Data Used for Identifying Potentially Highly Exposed Populations* (U.S. EPA, 1999).

Studies were chosen that were seen as useful and appropriate for estimating exposure factors for both adults and children. In conjunction with the *Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants* (U.S. EPA, 2005b), this handbook adopted the age group notation "X to <Y" (e.g., the age group 3 to <6 years is meant to span a 3-year time interval from a child's 3rd birthday up until the day before his or her 6th birthday). Every attempt was made to present the data for the recommended age groups. In cases where age group categories from the study authors did not match exactly with the U.S. EPA recommended age groups, the recommendations were matched as closely as possible. In some cases, data were limited, and age groups were lumped into bigger age categories to obtain adequate sample size. It is also recognized that dose-response data may not be available for many of the recommended age groupings. However, a standard set of age groups can assist in data collection efforts and provide focus for future research to better assess all significant variations in life stage (U.S. EPA, 2005b). To this date, no specific guidance is available with regard to age groupings for presenting adult data. Therefore, adult data (i.e., >21 years old) are presented using the age groups defined by the authors of the individual studies. No attempt was made to reanalyze the data using a consistent set of age groups. Therefore, in cases where data were analyzed by the U.S. EPA, age categories were defined as finely as possible based on adequacy of sample size. It is recognized that adults' activity patterns will vary with many factors including age, especially in the older adult population.

Certain studies described in this handbook are designated as "key," that is, the most up-to-date and scientifically sound for deriving recommendations for exposure factors. The recommended values for all exposure factors are based on the results of the key studies (see Section 1.6). Other studies are designated "relevant," meaning applicable or pertinent, but not necessarily the most important. As new data or analyses are published, "key" studies may be moved to the "relevant" category in future revisions because they are replaced by more up-to-date data or an analysis of improved quality. Studies may be classified as "relevant" for one or more of the following reasons: (1) they provide supporting data (e.g., older studies on food intake that may be useful for trend analysis); (2) they provide information related to the factor of interest (e.g., data on prevalence of breast-feeding); (3) the study design or approach makes the data less applicable to the population of interest (e.g., studies with small sample size, studies not conducted in the United States).

It is important to note that studies were evaluated based on their ability to represent the population for which the study was designed. The users of the handbook will need to evaluate the studies' applicability to their population of interest.

1.5.1. General Assessment Factors

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

1.5.2. Selection Criteria

The confidence ratings for the various exposure factor recommendations, and selection of the key studies that form the basis for these recommendations, were based on specific criteria within each of the five GAFs, as follows:

1) ***Soundness:*** *Scientific and technical procedures, measures, methods, or models employed to generate the information are reasonable for, and consistent with, the intended application.* The soundness of the experimental procedures or approaches in the study designs of the available studies was evaluated according to the following:
   a) **<u>Adequacy of the Study Approach Used</u>:** In general, more confidence was placed on experimental procedures or approaches that more likely or closely captured the desired measurement. Direct exposure data collection techniques, such as direct observation, personal monitoring devices, or other known methods were preferred where available. If studies utilizing direct measurement were not available, studies were selected that relied on validated indirect measurement methods such as surrogate measures (such as heart rate for

inhalation rate), and use of questionnaires. If questionnaires or surveys were used, proper design and procedures include an adequate sample size for the population under consideration, a response rate large enough to avoid biases, and avoidance of bias in the design of the instrument and interpretation of the results. More confidence was placed in exposure factors that relied on studies that gave appropriate consideration to these study design issues. Studies were also deemed preferable if based on primary data, but studies based on secondary sources were also included where they offered an original analysis. In general, higher confidence was placed on exposure factors based on primary data.

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

2) ***Applicability and Utility:*** *The information is relevant for the Agency's intended use. The applicability and utility of the available studies were evaluated based on the following criteria:*

a) **Focus on Exposure Factor of Interest:** Studies were preferred that directly addressed the exposure factor of interest or addressed related factors that have significance for the factor under consideration. As an example of the latter case, a selected study contained useful ancillary information concerning fat content in fish, although it did not directly address fish consumption.

b) **Representativeness of the Population:** More confidence was placed in studies that addressed the U.S. population. Data from populations outside the United States were sometimes included if behavioral patterns or other characteristics of exposure were similar. Studies seeking to characterize a particular region or demographic characteristic were selected, if appropriately representative of that population. In cases where data were limited, studies with limitations in this area were included, and limitations were noted in the handbook. Higher confidence ratings were given to exposure factors where the available data were representative of the population of interest. The risk or exposure assessor may need to evaluate whether these data may be used as suitable substitutes for their population of interest or whether there is a need to seek additional population-specific data.

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

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

3) ***Clarity and Completeness*****:** *The degree of clarity and completeness with which the data, assumptions, methods, quality assurance, sponsoring organizations and analyses employed to generate the information is documented.* Clarity and completeness were evaluated based on the following criteria:

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

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

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

4) ***Variability and Uncertainty:*** *The variability and uncertainty (quantitative and qualitative) in the information or the procedures, measures, methods, or models are evaluated and characterized.* Variability arises from true heterogeneity across people, places, or time and can affect the precision of exposure estimates and the degree to which they can be generalized. The types of variability include spatial, temporal, and inter-individual. Uncertainty represents a lack of knowledge about factors affecting exposure or risk and can lead to inaccurate or biased estimates of exposure. Increasingly probabilistic methods are being utilized to analyze variability and uncertainty independently as well as simultaneously. It is sometimes challenging to distinguish between variability and parameter uncertainty in this context as both can involve the distributions of a random variable. The types of uncertainty include scenario, parameter, and model. More information on variability and uncertainty is provided in Chapter 2 of this handbook. The uncertainty and variability associated with the studies were evaluated based on the following criteria:

a) **Variability in the Population:** Studies were sought that characterized any variability within populations. The variability associated with the recommended exposure factors is described in Section 1.6. Higher confidence ratings were given to exposure factors that were based on studies where variability was well characterized.

b) **Uncertainty:** Studies were sought with minimal uncertainty in the data, which was judged by evaluating all the considerations listed above. Studies were preferred that identified uncertainties, such as those due to possible measurement error. Higher confidence ratings were given to exposure factors based on studies where uncertainty had been minimized.

5) ***Evaluation and Review:*** *The information or the procedures, measures, methods, or models are independently verified, validated, and peer reviewed.* Relevant factors that were considered included:

a) **Peer Review:** Studies selected were those from the peer-reviewed literature and final government reports. Unpublished and internal or interim reports were avoided, where possible. but were used in some cases to supplement information in published literature or government reports.

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

1.6. APPROACH USED TO DEVELOP RECOMMENDATIONS FOR EXPOSURE FACTORS

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

1) ***Study Review and Evaluation:*** Key studies were evaluated in terms of both quality and relevance to specific populations (general U.S. population, age groups, sex, etc.). Section 1.5 describes the criteria for assessing the quality of studies.

2) ***Selection of One versus Multiple Key Studies:*** If only one study was classified as key for a particular factor, the mean value from that study was selected as the recommended central value for that population. If multiple key studies with reasonably equal quality, relevance, and study design information were available, a weighted mean (if appropriate, considering sample size and other statistical factors) of the studies was chosen as the recommended

mean value. Recommendations for upper percentiles, when multiple studies were available, were calculated as the mid-point of the range of upper percentile values of the studies for each age group where data were available. It is recognized that the mid-point of the range of upper percentiles may not provide the best estimate, but in the absence of raw data, more sophisticated analysis could not be performed.

3) ***Assessing Variability:*** The variability of the factor across the population is discussed. For recommended values, as well as for each of the studies on which the recommendations are based, variability was characterized in one or more of three ways: (1) as a table with various percentiles or ranges of values; (2) as analytical distributions with specified parameters; and/or (3) as a qualitative discussion. Analyses to fit standard or parametric distributions (e.g., normal, lognormal) to the exposure data have not been performed by the authors of this handbook, but have been reproduced as they were found in the literature. Recommendations on the use of these distributions were made where appropriate based on the adequacy of the supporting data. Table 1-1 presents the list of exposure factors and the way in which variability in the population has been characterized throughout this handbook (i.e., average, median, upper percentiles, multiple percentiles).

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

4) ***Assessing Uncertainty:*** Uncertainties are discussed in terms of data limitations, the range of circumstances over which the estimates were (or were not) applicable, possible biases in the values themselves, a statement about parameter uncertainties (measurement error, sampling error), and model or scenario uncertainties if models or scenarios were used to derive the recommended value. A more detailed discussion of variability and uncertainty for exposure factors is presented in Chapter 2 of this handbook.

5) ***Assigning Confidence Ratings:*** Finally, the U.S. EPA assigned a confidence rating of *low*, *medium*, or *high* to each recommended value in each chapter. This qualitative rating is not intended to represent an uncertainty analysis; rather, it represents the U.S. EPA's judgment on the quality of the underlying data used to derive the recommendation. This judgment was made using the GAFs described in Section 1.5. Table 1-2 provides an adaptation of the GAFs, as they pertain to the confidence ratings for the exposure factor recommendations. Clearly, there is a continuum from *low to high*, and judgment was used to assign a rating to each factor. It is important to note that these confidence ratings are based on the strengths and limitations of the underlying data and not on how these data may be used in a particular exposure assessment.

The study elements listed in Table 1-2 do not have the same weight when arriving at the overall confidence rating for the various exposure factors. The relative weight of each of these elements for the various factors was subjective and based on the professional judgment of the authors of this handbook.

Also, the relative weights depend on the exposure factor of interest. For example, the adequacy of the data collection period may be more important when determining usual intake of foods in a population, but it is not as important for factors where long-term variability may be small, such as tap water intake. In the case of tap water intake, the currency of the data was a critical element in determining the final rating. In general, most studies ranked high with regard to "level of peer review," "accessibility," "focus on the factor of interest," and "data pertinent to the United States" because the U.S. EPA specifically sought studies for the handbook that met these criteria.

The confidence rating is also a reflection of the ease at which the exposure factor of interest could be measured. This is taken into consideration under the *soundness* criterion. For example, soil ingestion by children can be estimated by measuring, in feces, the levels of certain elements found in soil. Body weight, however, can be measured directly, and it is, therefore, a more reliable measurement than estimation of soil ingestion. The fact that soil ingestion is more difficult to measure than body weight is reflected in the overall confidence rating given to both of these factors. In general, the better the methodology used to measure the exposure factor, the higher the confidence in the value.

Some exposure factors recommendations may have different confidence ratings depending on the population of interest. For example a lower confidence rating may be noted for some age groups for which sample sizes are small. As another example, a lower confidence rating was assigned to the recommendations as they would apply to long-term chronic exposures versus acute exposures because of the short-term nature of the data collection period. To the extent possible, these caveats were noted in the confidence rating tables.

6) ***Recommendation Tables:*** The U.S. EPA developed a table at the beginning of each chapter that summarizes the recommended values for the relevant factor. Table ES-1 of the Executive Summary of this handbook summarizes the principal exposure factors addressed in this handbook and provides the confidence ratings for each exposure factor.

1.7. SUGGESTED REFERENCES FOR USE IN CONJUNCTION WITH THIS HANDBOOK

Many of the issues related to characterizing exposure from selected exposure pathways have been addressed in a number of existing U.S. EPA documents. Some of these provide guidance while others demonstrate various aspects of the exposure process. These include, but are not limited to, the following references listed in chronological order:

- *Methods for Assessing Exposure to Chemical Substances, Volumes 1–13* (U.S. EPA, 1983-1989);
- *Standard Scenarios for Estimating Exposure to Chemical Substances During Use of Consumer Products* (U.S. EPA, 1986b, c);
- *Selection Criteria for Mathematical Models Used in Exposure Assessments: Surface Water Models* (U.S. EPA, 1987b);
- *Selection Criteria for Mathematical Models Used in Exposure Assessments: Groundwater Models* (U.S. EPA, 1988);
- *Risk Assessment Guidance for Superfund, Volume I, Part A, Human Health Evaluation Manual* (U.S. EPA, 1989b);
- *Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions* (U.S. EPA, 1990);
- *Risk Assessment Guidance for Superfund, Volume I, Part B, Development of Preliminary Remediation Goals* (U.S. EPA, 1991a);
- *Risk Assessment Guidance for Superfund, Volume I, Part C, Risk Evaluation of Remedial Alternatives* (U.S. EPA, 1991b);
- *Guidelines for Exposure Assessment* (U.S. EPA, 1992c);
- *Dermal Exposure Assessment: Principles and Applications* (U.S. EPA, 1992a);
- *Soil Screening Guidance* (U.S. EPA, 1996b);
- *Series 875 Occupational and Residential Exposure Test Guidelines—Final Guidelines—Group A—Application Exposure Monitoring Test Guidelines* (U.S. EPA, 1996a);
- *Series 875 Occupational and Residential Exposure Test Guidelines—Group B—Post Application Exposure Monitoring Test Guidelines* (U.S. EPA, 1998);
- *Policy for Use of Probabilistic Analysis in Risk Assessment at the U.S. Environmental Protection Agency* (U.S. EPA, 1997c);

- *Guiding Principles for Monte Carlo Analysis* (U.S. EPA, 1997b);
- *Sociodemographic Data for Identifying Potentially Highly Exposed Populations* (U.S. EPA, 1999);
- *Options for Development of Parametric Probability Distributions for Exposure Factors* (U.S. EPA, 2000a);
- *Risk Assessment Guidance for Superfund, Volume I, Part D, Standardized Planning, Reporting, and Review of Superfund Risk Assessments* (U.S. EPA, 2001b);
- *Risk Assessment Guidance for Superfund Volume III, Part A, Process for Conducting Probabilistic Risk Assessments* (U.S. EPA, 2001c)
- *Framework for Cumulative Risk Assessment* (U.S. EPA, 2003b);
- *Example Exposure Scenarios* (U.S. EPA, 2004a);
- *Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) and Related Compounds National Academy Sciences Review Draft* (U.S. EPA, 2003a);
- *Risk Assessment Guidance for Superfund, Volume I, Part E, Supplemental Guidance for Dermal Risk Assessment* (U.S. EPA, 2004b);
- *Cancer Guidelines for Carcinogen Risk Assessment* (U.S. EPA, 2005c);
- *Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens* (U.S. EPA, 2005e);
- *Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants* (U.S. EPA, 2005b);
- *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities* (U.S. EPA, 2005d);
- *Aging and Toxic Response: Issues Relevant to Risk Assessment* (U.S. EPA, 2005a);
- *A Framework for Assessing Health Risk of Environmental Exposures to Children* (U.S. EPA, 2006b);
- *Dermal Exposure Assessment: A Summary of EPA Approaches* (U.S. EPA, 2007b);
- *Child-Specific Exposure Factors Handbook* (U.S. EPA, 2008a);
- *Concepts, Methods, and Data Sources For Cumulative Health Risk Assessment of Multiple Chemicals, Exposures and Effects: A Resource Document* (U.S. EPA, 2007a);
- *Physiological Parameters Database for Older Adults (Beta 1.1)* (U.S. EPA, 2008b);
- *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual Part F, Supplemental Guidance for Inhalation Risk Assessment* (U.S. EPA, 2009b);
- *Draft Technical Guidelines Standard Operating Procedures for Residential Pesticide Exposure Assessment* (U.S. EPA, 2009a);
- *Stochastic Human Exposure and Dose Simulation (SHEDS)-Multimedia. Details of SHEDS-Multimedia Version 3: ORD/NERL's Model to Estimate Aggregate and Cumulative Exposures to Chemicals* (U.S. EPA, 2010); and
- *Recommended Use of Body Weight$^{3/4}$ (BW$^{3/4}$) as the Default Method in Derivation of the Oral Reference Dose (RfD)* (U.S. EPA, 2011).

These documents may serve as valuable information resources to assist in the assessment of exposure. Refer to them for more detailed discussion.

1.8. THE USE OF AGE GROUPINGS WHEN ASSESSING EXPOSURE

When this handbook was published in 1997, no specific guidance existed with regard to which age groupings should be used when assessing children's exposure. Age groupings varied from case to case and among Program Offices within the U.S. EPA. They depended on availability of data and were often based on professional judgment. More recently, the U.S. EPA has established a consistent set of age groupings and published guidance on this topic (U.S. EPA, 2005b). This revision of the handbook attempts to present data in a manner consistent with the U.S. EPA's recommended set of age groupings for children. The presentation of data for these fine age categories does not necessarily mean that every age category needs to be the subject of a particular assessment. It will depend on the objectives of the assessment and communications with toxicologists to identify the critical windows of susceptibility.

The development of standardized age bins for children was the subject of discussion in a 2000 workshop sponsored by the U.S. EPA Risk Assessment Forum. The workshop was titled *Issues Associated with Considering Developmental Changes in Behavior and Anatomy When Assessing Exposure to Children* (U.S. EPA, 2000b). The purpose of this workshop was to gain insight and input into factors that need to be considered when developing standardized age bins and to identify future research necessary to accomplish these goals.

Based upon consideration of the findings of the technical workshop, as well as analysis of available data, U.S. EPA developed guidance that established a set of recommended age groups for development of exposure factors for children entitled *Guidance for Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants* (U.S. EPA, 2005b). This revision of the handbook for individuals <21 years of age presents exposure factors data in a manner consistent with U.S. EPA's recommended set of childhood age groupings. The recommended age groups (U.S. EPA, 2005b) are as follows:

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
16 to <21 years

1.9. CONSIDERING LIFE STAGE WHEN CALCULATING EXPOSURE AND RISK

In recent years, there has been an increased concern regarding the potential impact of environmental exposures to children and other susceptible populations such as older adults and pregnant/lactating women. As a result, the U.S. EPA and others have developed policy and guidance and undertaken research to better incorporate life stage data into human health risk assessment (Brown et al., 2008). The *Child-Specific Exposure Factors Handbook* was published in 2008 to address the need to characterize children's exposures at various life stages (U.S. EPA, 2008a). Children are of special concern because (1) they consume more of certain foods and water per unit of body weight than adults; (2) they have a higher ratio of body surface area to volume than adults; and (3) they experience important, rapid changes in behavior and physiology that may lead to differences in exposure (Moya et al., 2004). Many studies have shown that young children can be exposed to various contaminants, including pesticides, during normal oral exploration of their environment (i.e., hand-to-mouth behavior) and by touching floors, surfaces, and objects such as toys (Garry, 2004; Eskenazi et al., 1999; Lewis et al., 1999; Nishioka et al., 1999; Gurunathan et al., 1998). Dust and tracked-in soil accumulate in carpets, where young children spend a significant amount of time (Lewis et al., 1999). Children living in agricultural areas may experience higher exposures to pesticides than do other children (Curwin et al., 2007). They may play in nearby fields or be exposed via consumption of contaminated human milk from their farmworker mothers (Eskenazi et al., 1999).

In terms of risk, children may also differ from adults in their vulnerability to environmental pollutants because of toxicodynamic differences (e.g., when exposures occur during periods of enhanced susceptibility) and/or toxicokinetic differences (i.e., differences in absorption, metabolism, and excretion) (U.S. EPA, 2000b). The immaturity of metabolic enzyme systems and clearance mechanisms in young children can result in longer half-lives of environmental contaminants (Clewell et al., 2004; Ginsberg et al., 2002). The cellular immaturity of children and the ongoing growth processes account for elevated risk (American Academy of Pediatrics, 1997). Toxic chemicals in the environment can cause neurodevelopmental disabilities, and the developing brain can be particularly sensitive to environmental contaminants. For example, elevated blood lead levels and prenatal exposures to even relatively low levels of lead can result in behavior disorders and reductions of intellectual function in children (Landrigan et al., 2005). Exposure to high levels of methylmercury can result in developmental disabilities (e.g., intellectual deficiency, speech disorders, and sensory disturbances) among children (Myers and Davidson, 2000). Other authors have described the importance of exposure timing (i.e., pre-conceptional, prenatal, and postnatal) and how it affects the outcomes observed (Selevan et al., 2000). Exposures during these critical windows of development and age-specific behaviors and physiological factors can lead to differences in response (Makri et al., 2004). Fetal exposures can occur from the mobilization of chemicals of maternal body burden and transfer of those chemicals across the placenta (Makri et al., 2004). Absorption through the gastrointestinal tract is more efficient in neonates and infants, making ingestion exposures a significant route of exposure during the first year of age (Makri et al., 2004).

It has also been suggested that higher levels of exposure to indoor air pollution and allergens among inner-city children compared to non-inner-city children may explain the difference in asthma levels between these two groups (Breysse et al., 2005). With respect to contaminants that are carcinogenic via a mutagenic mode of action (MOA), the U.S. EPA has found that childhood is a particularly sensitive period of development in which cancer potencies per year of exposure can be an order of magnitude higher than during adulthood (U.S. EPA, 2005e).

A framework for considering life stages in human health risk assessments was developed by the U.S. EPA in the report entitled *A Framework for Assessing Health Risks of Environmental Exposures to Children* (U.S. EPA, 2006b). Life stages are defined as "temporal stages (or intervals) of life that have distinct anatomical, physiological, behavioral, and/or functional characteristics that contribute to potential differences in environmental exposures" (Brown et al., 2008). One way to understand the differential exposures among life stages is to study the data using age binning or age groups as it is the recommendation for childhood exposures. Although the framework discusses the importance of incorporating life stages in the evaluation of risks to children, the approach can also be applied to other life stages that may have their own unique susceptibilities. For example, older individuals may experience differential exposures and risks to environmental contaminants due to biological changes that occur during aging, disease status, drug interactions, different exposure patterns, and activities. More information on the toxicokinetic and toxicodynamic impact of environmental agents in older adults can be found in U.S. EPA's document entitled *Aging and Toxic Response: Issues Relevant to Risk Assessmen*t (U.S. EPA, 2005a). The need to better characterize differential exposures of the older adult population to environmental agents was recognized at the U.S. EPA's workshop on the development of exposure factors for the aging (U.S. EPA, 2007c). A panel of experts in the fields of gerontology, physiology, exposure assessment, risk assessment, and behavioral science discussed existing data, data gaps, and current relevant research on the behavior and physiology of older adults, as well as practical considerations of the utility of developing an exposure factors handbook for the aging (U.S. EPA, 2007c). Pregnant and lactating women may also be a life stage of concern due to physiological changes during pregnancy and lactation. For example, lead is mobilized from the maternal skeleton during pregnancy and the postpartum period, increasing the chances for fetal lead exposure (Gulson et al., 1999).

The U.S. EPA encourages the consideration of all life stages and endpoints to ensure that vulnerabilities during specific time periods are taken into account (Brown et al., 2008). Although the importance of assessing risks from environmental exposures to all susceptible populations is recognized, most of the guidance developed thus far relates to children. Furthermore, it is recognized that there is a lack of dose-response data to evaluate differential responses at various life stages (e.g., age groups, pregnant/lactating mothers, older populations). A key component of U.S. EPA's *Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants* (U.S. EPA, 2005b) involves the need to sum age-specific exposures across time when assessing long-term exposure, as well as integrating these age-specific exposures with age-specific differences in toxic potency in those cases where information exists to describe such differences: an example is carcinogens that act via a mutagenic mode of action [*Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens* – (U.S. EPA, 2005e)]. When assessing chronic risks (i.e., exposures greater than 10% of human lifespan), rather than assuming a constant level of exposure for 70 years (usually consistent with an adult level of exposure), the Agency is now recommending that assessors calculate chronic exposures by summing time-weighted exposures that occur at each life stage; this handbook provides data arrayed by childhood age in order to follow this new guidance (U.S. EPA, 2005e). This approach is expected to increase the accuracy of risk assessments, because it will take into account life stage differences in exposure. Depending on whether body-weight-adjusted childhood exposures are either smaller or larger compared to those for adults, calculated risks could either decrease or increase when compared with the historical approach of assuming a lifetime of a constant adult level of exposure.

The *Supplemental Guidance* report also recommended that in those cases where age-related differences in toxicity were also found to occur, differences in both toxicity and exposure would need to be integrated across all relevant age intervals (U.S. EPA, 2005e). This guidance describes such a case for carcinogens that act via a mutagenic mode of action, where age dependent adjustments factors (ADAFs) of 10× and 3× are recommended for children ages birth to <2 years, and 2 to <16 years, respectively, when there is exposure during those years, and available data are insufficient to derive chemical-specific adjustment factors.

Table 1-3, along with Chapter 6 of the *Supplemental Guidance* (U.S. EPA, 2005e) report, have been developed to help the reader understand how to use the new sets of exposure and potency age groupings when calculating risk through the integration of life stage specific changes in exposure and potency for mutagenic carcinogens.

Thus, Table 1-3 presents Lifetime Cancer Risk (for a population with average life expectancy of 70 years) = ∑ (Exposure × Duration/70 years × Potency × ADAF) summed across all the age groups. This is a departure from the way cancer risks have historically been calculated based upon the premise that risk is proportional to the daily average of the long-term adult dose.

1.10. FUNDAMENTAL PRINCIPLES OF EXPOSURE ASSESSMENT

An exposure assessment is the "process of estimating or measuring the magnitude, frequency, and duration of exposure to an agent, along with the number and characteristics of the population exposed" (Zartarian et al., 2007). The definition of exposure as used by the International Program on Chemical Safety (WHO, 2001) is the "contact of an organism with a chemical or physical agent, quantified as the amount of chemical available at the exchange boundaries of the organism and available for absorption." The term "agent" refers to a chemical, biological, or physical entity that contacts a target. The "target" refers to any physical, biological, or ecological object exposed to an agent. In the case of human exposures, the contact occurs with the visible exterior of a person (i.e., target) such as the skin, and openings such as the mouth, nostrils, and lesions. The process by which an agent crosses an outer exposure surface of a target without passing an absorption barrier (i.e., through ingestion or inhalation) is called an intake. The resulting dose is the intake dose. The intake dose is sometimes referred to in the literature as the administered dose or potential dose.

The terms "exposure" and "dose" are very closely related and, therefore, are often confused (Zartarian et al., 2007). Dose is the amount of agent that enters a target in a specified period of time after crossing a contact boundary. An exposure does not necessarily leads to a dose. However, there can be no dose without a corresponding exposure (Zartarian et al., 2007). Figure 1-1 illustrates the relationship between exposure and dose.

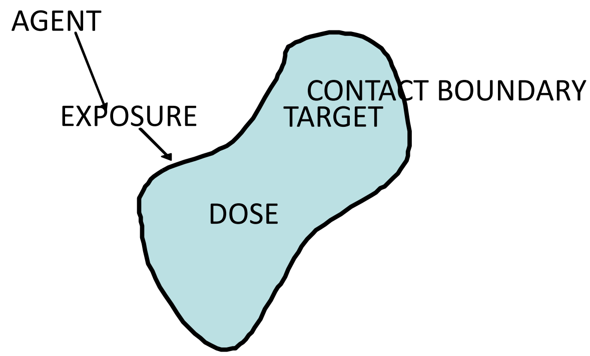

Figure 1-1. Conceptual Drawing of Exposure and Dose Relationship (Zartarian et al., 2007).

In other words, the process of an agent entering the body can be described in two steps: contact (exposure) followed by entry (crossing the boundary). In the context of environmental risk assessment, risk to an individual or population can be represented as a continuum from the source through exposure to dose to effect as shown in Figure 1-2 (Ott, 2007; WHO, 2006; U.S. EPA, 2003c). The process begins with a chemical or agent released from a source into the environment. Once in the environment, the agent can be transformed and transported through the environment via air, water, soil, dust, and diet (i.e., exposure pathway). Fate and transport mechanisms result in various chemical concentrations with which individuals may come in contact. Individuals encounter the agent either through inhalation, ingestion, or skin/eye contact (i.e., exposure route). The individual's activity patterns as well as the concentration of the agent will determine the magnitude, frequency, and duration of the exposure. The exposure becomes an absorbed dose when the agent crosses an absorption barrier (e.g., skin, lungs, gut). Other terms used in the literature to refer to absorbed dose include internal dose, bioavailable dose, delivered dose, applied dose, active dose, and biologically effective dose (Zartarian et al., 2007). When an agent or its metabolites interact with a target tissue, it becomes a target tissue dose, which may lead to an adverse health outcome. The text under the boxes in Figure 1-2 indicates the specific information that may be needed to characterize each box.

This approach has been used historically in exposure assessments and exposure modeling. It is usually referred to as source-to-dose approach. In recent years, person-oriented approaches and models have gained popularity. This approach is aimed at accounting for cumulative and aggregate exposures to individuals (Georgopoulos, 2008; Price et al., 2003a). The person-oriented approach can also take advantage of information about the individual's susceptibility to environmental factors (e.g., genetic differences) (Georgopoulos, 2008).

There are three approaches to calculate exposures: (1) the point-of-contact approach, (2) the scenario evaluation approach, and (3) the dose reconstruction approach (U.S. EPA, 1992c). The data presented in this handbook are generally useful for evaluating exposures using the scenario approach. There are advantages and disadvantages associated with each approach. Although it is not the purpose of this handbook to provide guidance on how to conduct an exposure assessment, a brief description of the approaches is provided below.

The point-of-contact approach, or direct approach, involves measurements of chemical concentrations at the point where exposure occurs (i.e., at the interface between the person and the environment). This chemical concentration is coupled with information on the length of contact with each chemical to calculate exposure. The scenario evaluation approach, or the indirect approach, utilizes data on chemical concentration, frequency, and duration of exposure as well as information on the behaviors and characteristics of the exposed life stage. The third approach, dose reconstruction, allows exposure to be estimated from dose, which can be reconstructed through the measurement of biomarkers of exposure. A biomarker of exposure is a chemical, its metabolite, or the product of an interaction between a chemical and some target molecule or cell that is measured in a compartment in an organism (NRC, 2006). Biomonitoring is becoming a tool for identifying, controlling, and preventing human exposures to environmental chemicals (NRC, 2006). For example, blood lead concentrations and the associated health effects were used by the U.S. EPA in its efforts to reduce exposure to lead in gasoline. The Centers for Disease Control and Prevention conducts biomonitoring studies to help identify chemicals that are both present in the environment and in human tissues (NRC, 2006). Biomonitoring studies also assist public health officials in studying distributions of exposure in a population and how they change overtime. Biomonitoring data can be converted to exposure using pharmacokinetic modeling (NRC, 2006). Although biomonitoring can be a powerful tool, interpretation of the data is difficult. Unlike the other two approaches, biomonitoring provides information on internal doses integrated across environmental pathways and media. Interpretation of these data requires knowledge and understanding of how the chemicals are absorbed, excreted, and metabolized in the biological system, as well as the properties of the chemicals and their metabolites (NRC, 2006). The interpretation of biomarker data can be further improved by the development of other cellular and molecular approaches to include advances in genomics, proteomics, and other approaches that make use of molecular-environmental interactions (Lioy et al., 2005). Physiological parameters can also vary with life stage, age, sex, and other demographic information (Price et al., 2003b). Physiologic and metabolic factors and how they vary with life stage have been the subject of recent research. Pharmacokinetic models are frequently developed from data obtained from young adults. Therapeutic drugs have been used as surrogates to study pharmacokinetic differences in fetuses, children, and adults (Ginsberg et al., 2004). Specific considerations of susceptibilities for other populations (e.g., children, older adults) require knowledge of the physiological parameters that most influence the disposition of the chemicals in the body (Thompson et al., 2009). Physiological parameters include alveolar ventilation, cardiac output, organ and tissue weights and volumes, blood flows to organs and tissues, clearance parameters, and body composition (Thompson et al., 2009). Price et al. (2003b) developed a tool for capturing the correlation between organs and tissue and compartment volumes, blood flows, body weight, sex, and other demographic information. A database that records key, age-specific pharmacokinetic model inputs for healthy older adults and for older adults with conditions such as diabetes, chronic obstructive pulmonary disease, obesity, heart disease, and renal disease has been developed by the U.S. EPA (Thompson et al., 2009; U.S. EPA, 2008b).

Computational exposure models can play an important role in estimating exposures to environmental chemicals (Sheldon and Cohen Hubal, 2009). In general, these models combine measurements of the concentration of the chemical agent in the environment (e.g., air, water, soil, food) with information about the individual's activity patterns to estimate exposure (WHO, 2005). Several models have been developed and may be used to support risk management decisions. For example, the U.S. EPA SHEDS model is a probabilistic model that simulates daily activities to predict distributions of daily exposures in a population (U.S. EPA, 2010). Other models such as the Modeling Environment for Total Risk Studies incorporates and expands the approach used by SHEDS and considers multiple routes of exposure (Georgopoulos and Lioy, 2006).

1.10.1. Exposure and Dose Equations

Exposure can be quantified by multiplying the concentration of an agent times the duration of the contact. Exposure can be instantaneous when the contact between an agent and a target occurs at a single point in time and space (Zartarian et al., 2007). The summation of instantaneous exposures over the exposure duration is called the time-integrated exposure (Zartarian et al., 2007). Equation 1-1 shows the time-integrated exposure.

$$E = \int_{t_1}^{t_2} C(t)dt \qquad \text{(Eqn. 1-1)}$$

where:

E = Time-integrated exposure (mass/volume),
$t_2 - t_1$ = Exposure duration (ED) (time), and
C = Exposure concentration as a function of time (mass/volume).

Dividing the time-integrated exposure by the exposure duration, results in the time-averaged exposure (Zartarian et al., 2007).

Dose can be classified as an intake dose or an absorbed dose (U.S. EPA, 1992c). Starting with a general integral equation for exposure, several dose equations can be derived depending upon boundary assumptions. One of the more useful of these derived equations is the average daily dose (ADD). The ADD, which is used for many non-cancer effects, averages exposures or doses over the period of time exposure occurred. The ADD can be calculated by averaging the intake dose over body weight and an averaging time as shown in Equations 1-2 and 1-3.

$$ADD = \frac{Intake\ Dose}{Body\ Weight\ \ x\ \ Averaging\ Time} \qquad \text{(Eqn. 1-2)}$$

The exposure can be expressed as follows:

$$\text{Intake Dose} = C \times IR \times ED \qquad \text{(Eqn. 1-3)}$$

where:

C = Concentration of the Agent (mass/volume),
IR = Intake Rate (mass/time), and
ED = Exposure Duration (time).

Concentration of the agent is the mass of the agent in the medium (air, food, soil, etc.) per unit volume contacting the body and has units of mass/volume or mass/mass.

The intake rate refers to the rates of inhalation, ingestion, and dermal contact, depending on the route of exposure. For ingestion, the intake rate is simply the amount of contaminated food ingested by an individual during some specific time period (units of mass/time). Much of this handbook is devoted to rates of ingestion for some broad classes of food. For inhalation, the intake rate is that at which contaminated air is inhaled. Factors presented in this handbook that affect dermal exposure are skin surface area and estimates of the amount of solids that adheres to the skin, film thickness of liquids to skin, transfer of residues, and skin thickness. It is important to note that there are other key factors in the calculation of dermal exposures that are not covered in this handbook (e.g., chemical-specific absorption factors).

The exposure duration is the length of time of contact with an agent. For example, the length of time a person lives in an area, frequency of bathing, time spent indoors versus outdoors, and in various microenvironments, all affect the exposure duration. Chapter 16, Activity Factors, gives some examples of population behavior and macro and micro activities that may be useful for estimating exposure durations.

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

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

Cancer risks have traditionally been calculated in those cases where a linear non-threshold model is assumed, in terms of lifetime probabilities by utilizing dose values presented in terms of lifetime ADDs (LADDs). The LADD takes the form of Equation 1-2, with lifetime replacing averaging time. While the use of LADDs may be appropriate when developing screening-level estimates of cancer risk, the U.S. EPA recommends that risks should be calculated by integrating exposures or risks throughout all life stages (U.S. EPA, 1992c).

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

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

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

The body weight to be used in Equation 1-2 depends on the units of the exposure data presented in this handbook. For example, for food ingestion, the body weights of the surveyed populations were known in the USDA and NHANES surveys, and they were explicitly factored into the food intake data in order to calculate the intake as g/kg body weight-day. In this case, the body weight has already been included in the "intake rate" term in Equation 1-3, and the exposure assessor does not need to explicitly include body weight.

The units of intake in this handbook for the incidental ingestion of soil and dust are not normalized to body weight. In this case, the exposure assessor will need to use (in Equation 1-2) the average weight of the exposed population during the time when the exposure actually occurs. When making body-weight assumptions, care must be taken that the values used for the population parameters in the dose-response analysis are consistent with the population parameters used in the exposure analysis. Intraspecies adjustments based on life stage can be made using a correction factor (CF) (U.S. EPA, 2011, 2006b). Appendix 1A of this chapter discusses these adjustments in more detail. Some of the parameters (primarily concentrations) used in estimating exposure are exclusively site specific, and, therefore, default recommendations should not be used. It should be noted that body weight is correlated with food consumption rates, body surface area, and inhalation rates (for more information, see Chapters 6, 7, 9, 10, 11, 12, 13, and 14).

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

- The intake rate can be based on an individual event (e.g., serving size per event). The duration should be based on the number of events or, in this case, meals.
- The intake rate also can be based on a long-term average, such as 10 g/day. In this case, the duration should be based on the total time interval over which the exposure occurs.

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

Inhalation dosimetry is employed to derive the human equivalent exposure concentrations on which inhalation unit risks (IURs), and reference concentrations (RfCs), are based (U.S. EPA, 1994). U.S. EPA has traditionally approximated children's respiratory exposure by using adult values, although a recent review (Ginsberg et al., 2005) concluded that there may be some cases where young children's greater inhalation rate per body weight or pulmonary surface area as compared to adults can result in greater exposures than adults. The implications of this difference for inhalation dosimetry and children's risk assessment were discussed at a peer involvement workshop hosted by the U.S. EPA in 2006 (Foos et al., 2008).

Consideration of life stage-particular physiological characteristics in the dosimetry analysis may result in a refinement to the human equivalent concentration (HEC) to ensure relevance in risk assessment across life stages, or might conceivably conclude with multiple HECs, and corresponding IUR values (e.g., separate for childhood and adulthood) (U.S. EPA, 2005e). The RfC methodology, which is described in *Methods for Derivation of Inhalation Reference Concentrations and Applications of Inhalation Dosimetry* (U.S. EPA, 1994), allows the user to incorporate population-specific assumptions into the models. Refer to U.S. EPA guidance (U.S. EPA, 1994) on how to make these adjustments.

There are no specific exposure factor assumptions in the derivation of RfDs for susceptible populations. With regard to childhood exposures for a susceptible population, for example, the assessment of the potential for adverse health effects in infants and children is part of the overall hazard and dose-response assessment for a chemical. Available data pertinent to children's health risks are evaluated along with data on adults and the no-observed-adverse-effect level (NOAEL) or benchmark dose (BMD) for the most sensitive critical effect(s), based on consideration of all health effects. By doing this, protection of the health of children will be considered along with that of other sensitive populations. In some cases, it is appropriate to evaluate the potential hazard to a susceptible population (e.g., children) separately from the assessment for the general population or other population groups. For more information regarding life stage-specific considerations for assessing children exposures, refer to the U.S. EPA report entitled *Framework for Assessing Health Risk of Environmental Exposures to Children* (U.S. EPA, 2006b).

1.10.2. Use of Exposure Factors Data in Probabilistic Analyses

Probabilistic risk assessment provides a range and likelihood estimate of risk rather than a single point estimate. It is a tool that can provide additional information to risk managers to improve decision making. Although this handbook is not intended to provide complete guidance on the use of Monte Carlo and other probabilistic analyses, some of the data in this handbook may be appropriate for use in probabilistic assessments. More detailed information on treating variability and uncertainty is discussed in Chapter 2 of this handbook. The use of Monte Carlo or other probabilistic analysis requires characterization of the variability of exposure factors and requires the selection of distributions or histograms for the input parameters of the dose equations presented in Section 1.10.1. The following suggestions are provided for consideration when using such techniques:

- The exposure assessor should only consider using probabilistic analysis when there are credible distribution data (or ranges) for the factor under consideration. Even if these distributions are known, it may not be necessary to apply this technique. For example, if only average exposure values are needed, these can often be computed accurately by using average values for each of the input parameters unless a non-linear model is used. Generally, exposure assessments follow a tiered approach to ensure the efficient use of resources. They may start with very simple techniques and move to more sophisticated models. The level of assessment needed can be determined initially during the problem formulation. There is also a tradeoff between the level of sophistication and the need to make timely decisions (NRC, 2009). Probabilistic analysis may not be necessary when conducting assessments for the first tier, which is typically done for screening purposes, i.e., to determine if unimportant pathways can be eliminated. In this case, bounding estimates can be calculated using maximum or near maximum values for each of the input parameters. Alternatively, the assessor may use the maximum values for those parameters that have the greatest variance.
- The selection of distributions can be highly site-specific and dependent on the purpose of the assessment. In some cases, the selection of distributions is driven by specific legislation. It will always involve some degree of judgment. Distributions derived from national data may not represent local conditions. Also, distributions may be representative of some age groups, but not representative when finer age categories are used. The assessor should evaluate the distributional data to ensure that it is representative of the population that needs to be characterized. In cases where site-specific data are available, the assessor may need to evaluate their quality and applicability. The assessor may decide to use distributional data drawn from the national or other surrogate population. In this case, it is important that the assessor address the extent to which local conditions may differ from the surrogate data.
- It is also important to consider the independence/dependence of variables and data used in a simulation. For example, it may

be reasonable to assume that ingestion rate and contaminant concentration in foods are independent variables, but ingestion rate and body weight may or may not be independent.

In addition to a qualitative statement of uncertainty, the representativeness assumption should be appropriately addressed as part of a sensitivity analysis. Distribution functions used in probabilistic analysis may be derived by fitting an appropriate function to empirical data. In doing this, it should be recognized that in the lower and upper tails of the distribution, the data are scarce, so that several functions, with radically different shapes in the extreme tails, may be consistent with the data. To avoid introducing errors into the analysis by the arbitrary choice of an inappropriate function, several techniques can be used. One technique is to avoid the problem by using the empirical data themselves rather than an analytic function. Another is to do separate analyses with several functions that have adequate fit but form upper and lower bounds to the empirical data. A third way is to use truncated analytical distributions. Judgment must be used in choosing the appropriate goodness-of-fit test.

Information on the theoretical basis for fitting distributions can be found in a standard statistics text, [e.g., Gilbert (1987), among others]. Off-the-shelf computer software can be used to statistically determine the distributions that fit the data. Other software tools are available to identify outliers and for conducting Monte Carlo simulations.

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

- keep that variable constant at its central value;
- assume several values within the range of values for the exposure factor;
- calculate a point estimate(s) instead of using probabilistic analysis; and
- assume a distribution. (The rationale for the selection of a distribution should be discussed at length.) The effects of selecting a different, but equally probable distribution should be discussed. There are, however, cases where assuming a distribution may introduce considerable amount of uncertainty. These include:
    - data are missing or very limited for a key parameter;
    - data were collected over a short time period and may not represent long-term trends (the respondent's usual behavior)—examples include food consumption surveys; activity pattern data;
    - data are not representative of the population of interest because sample size was small or the population studied was selected from a local area and was, therefore, not representative of the area of interest; for example, soil ingestion by children; and
    - ranges for a key variable are uncertain due to experimental error or other limitations in the study design or methodology; for example, soil ingestion by children.

1.11. AGGREGATE AND CUMULATIVE EXPOSURES

The U.S. EPA recognizes that individuals may be exposed to mixtures of chemicals both indoors and outdoors through more than one pathway. New directions in risk assessments in the U.S. EPA put more emphasis on total exposures via multiple pathways (U.S. EPA, 2007a, 2003c). Assessments that evaluate a single agent or stressor across multiple routes are not considered cumulative risk assessments. These are defined by the Food Quality Protection Act as aggregate risk assessments and can provide useful information to cumulative assessments (U.S. EPA, 2003c). Concepts and considerations to conduct aggregate risk assessments are provided in the U.S. EPA document entitled *General Principles for Performing Aggregate Exposure and Risk Assessments* (U.S. EPA, 2001a).

Cumulative exposure is defined as the exposure to multiple agents or stressors via multiple routes. In the context of risk assessment, it means that risks from multiple routes and agents need to be combined, not necessarily added (U.S. EPA, 2003b). Analysis needs to be conducted on how the various agents and stressors interact (U.S. EPA, 2003b).

In order to achieve effective risk assessment and risk management decisions, all media and routes of exposure should be assessed (NRC, 2009, 1991). Over the last several years, the U.S. EPA has developed a methodology for assessing risk from multiple chemicals (U.S. EPA, 2000c, 1986a). For more information, refer to the U.S. EPA's Framework for Cumulative Risk Assessment (U.S. EPA, 2003b). The recent report by the NAS also recommends the development of approaches to incorporate the interactions between chemical and non-chemical stressors (NRC, 2009).

1.12. ORGANIZATION OF THE HANDBOOK

All the chapters of this handbook have been organized in a similar fashion. An introduction is provided that discusses some general background information about the exposure factor. This discussion is followed by the recommendations for that exposure factor including summary tables of the recommendations and confidence ratings. The goal of the summary tables is to present the data in a simplified fashion by providing mean and upper percentile estimates and referring the reader to more detailed tables with more percentile estimates or other demographic information (e.g., sex) at the end of the chapter. Because of the large number of tables in this handbook, tables that include information other than the recommendations and confidence ratings are presented at the end of each chapter, before the appendices, if any. Following the recommendations, the key studies are summarized. Relevant data on the exposure factor are also provided. These data are presented to provide the reader with added perspective on the current state-of-knowledge pertaining to the exposure factor of interest. Summaries of the key and relevant studies include discussions about their strengths and limitations. Note that because the studies often were performed for reasons unrelated to developing the factor of interest, the attributes that were characterized as limitations might not be limitations when viewed in the context of the study's original purpose.

The handbook is organized as follows:

Chapter 1	Introduction—includes discussions about general concepts in exposure assessments as well as the purpose, scope, and contents of the handbook.
Chapter 2	Variability and Uncertainty—provides a brief overview of the concepts of variability and uncertainty and directs the reader to other references for more in-depth information.
Chapter 3	Ingestion of Water and Other Select Liquids—provides information on drinking water consumption and data on intake of select liquids for the general population and various demographic groups; also provides data on intake of water while swimming.
Chapter 4	Non-dietary Ingestion—presents data on mouthing behavior necessary to estimate non-dietary exposures.
Chapter 5	Soil and Dust Ingestion—provides information on soil and dust ingestion for both adults and children.
Chapter 6	Inhalation Rates—presents data on average daily inhalation rates and activity-specific inhalation rates for the general population and various demographic groups.
Chapter 7	Dermal Exposure Factors—presents information on body surface area and solids adherence to the skin, as well as data on other non-chemical-specific factors that may affect dermal exposure.
Chapter 8	Body Weight—provides data on body weight for the general population and various demographic groups.
Chapter 9	Intake of Fruits and Vegetables—provides information on total fruit and vegetable consumption as well as intake of individual fruits and vegetables for the general population and various demographic groups.
Chapter 10	Intake of Fish and Shellfish—provides information on fish consumption for the general population, recreational freshwater and marine populations, and various demographic groups.
Chapter 11	Intake of Meats, Dairy Products, and Fats—provides information on meat, dairy products, and fats consumption for the general population and various demographic groups.
Chapter 12	Intake of Grain Products—provides information on grain consumption for the general population and various demographic groups.
Chapter 13	Intake of Home-produced Foods—provides information on home-produced food consumption for the general population and various demographic groups.
Chapter 14	Total Food Intake—provides information on total food consumption for the general population and various demographic groups; information on the composition of the diet is also provided.

Chapter 15 Human Milk Intake—presents data on human milk consumption for infants at various life stages.

Chapter 16 Activity Factors—presents data on activity patterns for the general population and various demographic groups.

Chapter 17 Consumer Products—provides information on frequency, duration, and amounts of consumer products used.

Chapter 18 Life Expectancy—presents data on the projected length of a lifetime, based on age and demographic factors.

Chapter 19 Building Characteristics—presents information on both residential and commercial building characteristics necessary to assess exposure to indoor air pollutants.

Figure 1-3 provides a schematic diagram that shows the linkages of a select number of exposure pathways with the exposure factors presented in this handbook and the corresponding exposure routes. Figure 1-4 provides a roadmap to assist users of this handbook in locating recommended values and confidence ratings for the various exposure factors presented in these chapters.

1.13. REFERENCES FOR CHAPTER 1

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Table 1-1. Availability of Various Exposure Metrics in Exposure Factors Data

Exposure Factors	Chapter	Average	Median	Upper Percentile	Multiple Percentiles
Ingestion of water and other select liquids (Chapter 3)	3	✓	✓	✓	✓
Non-dietary ingestion	4	✓	✓	✓	✓
Soil and dust ingestion	5	✓		✓[a]	
Inhalation rate	6	✓	✓	✓	✓
Surface area Soil adherence	7 7	✓ ✓	✓	✓	✓
Body weight	8	✓	✓	✓	✓
Intake of fruits and vegetables	9	✓	✓	✓	✓
Intake of fish and shellfish	10	✓	✓	✓	✓
Intake of meats, dairy products, and fats	11	✓	✓	✓	✓
Intake of grain products	12	✓	✓	✓	✓
Intake of home produced foods	13	✓	✓	✓	✓
Total food intake	14	✓	✓	✓	✓
Human milk intake	15	✓		✓	
Total time indoors	16	✓			
Total time outdoors	16	✓			
Time showering	16	✓	✓	✓	✓
Time bathing	16	✓	✓	✓	✓
Time swimming	16	✓	✓	✓	✓
Time playing on sand/gravel	16	✓	✓	✓	✓
Time playing on grass	16	✓	✓	✓	✓
Time playing on dirt	16	✓	✓	✓	✓
Occupational mobility	16		✓		
Population mobility	16	✓	✓	✓	✓
Life expectancy	18	✓			
Volume of residence or building Air exchange rates	19 19		✓ ✓	✓[b] ✓[b]	

✓ = Data available.
[a] Including soil pica and geophagy.
[b] Lower percentile.

Table 1-2. Criteria Used to Rate Confidence in Recommended Values

General Assessment Factors	Elements Increasing Confidence	Elements Decreasing Confidence
Soundness		
Adequacy of Approach	The studies used the best available methodology and capture the measurement of interest.	There are serious limitations with the approach used; study design does not accurately capture the measurement of interest.
	As the sample size relative to that of the target population increases, there is greater assurance that the results are reflective of the target population.	Sample size too small to represent the population of interest.
	The response rate is greater than 80% for in-person interviews and telephone surveys, or greater than 70% for mail surveys.	The response rate is less than 40%.
	The studies analyzed primary data.	The studies are based on secondary sources.
Minimal (or defined) Bias	The study design minimizes measurement errors.	Uncertainties with the data exist due to measurement error.
Applicability and Utility		
Exposure Factor of Interest	The studies focused on the exposure factor of interest.	The purpose of the studies was to characterize a related factor.
Representativeness	The studies focused on the U.S. population.	Studies are not representative of the U.S. population.
Currency	The studies represent current exposure conditions.	Studies may not be representative of current exposure conditions.
Data Collection Period	The data collection period is sufficient to estimate long-term behaviors.	Shorter data collection periods may not represent long-term exposures.
Clarity and Completeness		
Accessibility	The study data are publicly available.	Access to the primary data set was limited.
Reproducibility	The results can be reproduced, or methodology can be followed and evaluated.	The results cannot be reproduced, the methodology is hard to follow, and the author(s) cannot be located.
Quality Assurance	The studies applied and documented quality assurance/quality control measures.	Information on quality assurance/control was limited or absent.

Table 1-2. Criteria Used to Rate Confidence in Recommended Values (continued)

General Assessment Factors	Increasing Confidence	Decreasing Confidence
Variability and Uncertainty		
Variability in Population	The studies characterize variability in the population studied.	The characterization of variability is limited.
Uncertainty	The uncertainties are minimal and can be identified. Potential bias in the studies are stated or can be determined from the study design.	Estimates are highly uncertain and cannot be characterized. The study design introduces biases in the results.
Evaluation and Review		
Peer Review	The studies received a high level of peer review (e.g., they are published in peer-reviewed journals).	The studies received limited peer review.
Number and Agreement of Studies	The number of studies is greater than three. The results of studies from different researchers are in agreement.	The number of studies is one. The results of studies from different researchers are in disagreement.

Table 1-3. Age-Dependent Potency Adjustment Factor by Age Group for Mutagenic Carcinogens

Exposure Age Group[a]	Exposure Duration (year)	Age-Dependent Potency Adjustment Factor
Birth to <1 month	0.083	10×
1 <3 months	0.167	10×
3 <6 months	0.25	10×
6 <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 to <70 years)	49	1×

[a] U.S. EPA's recommended childhood age groups (excluding ages >21 years).

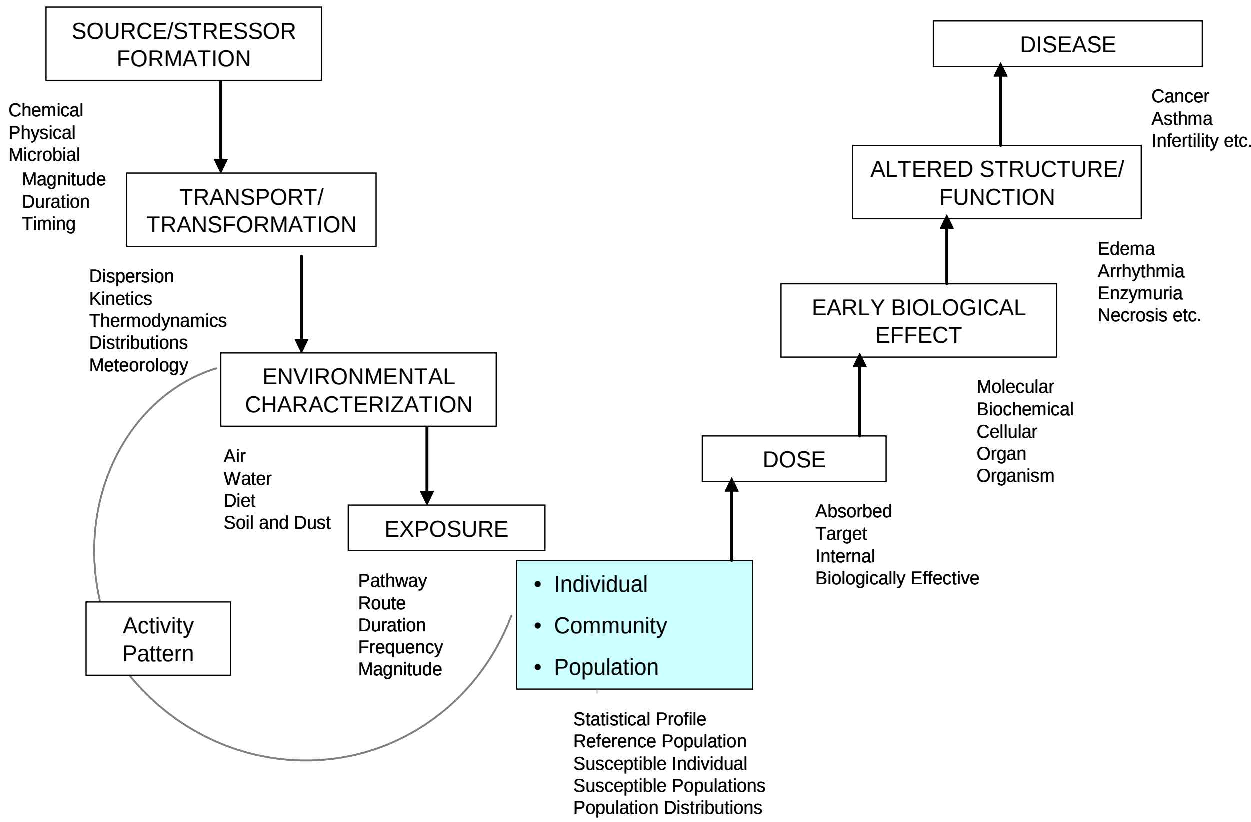
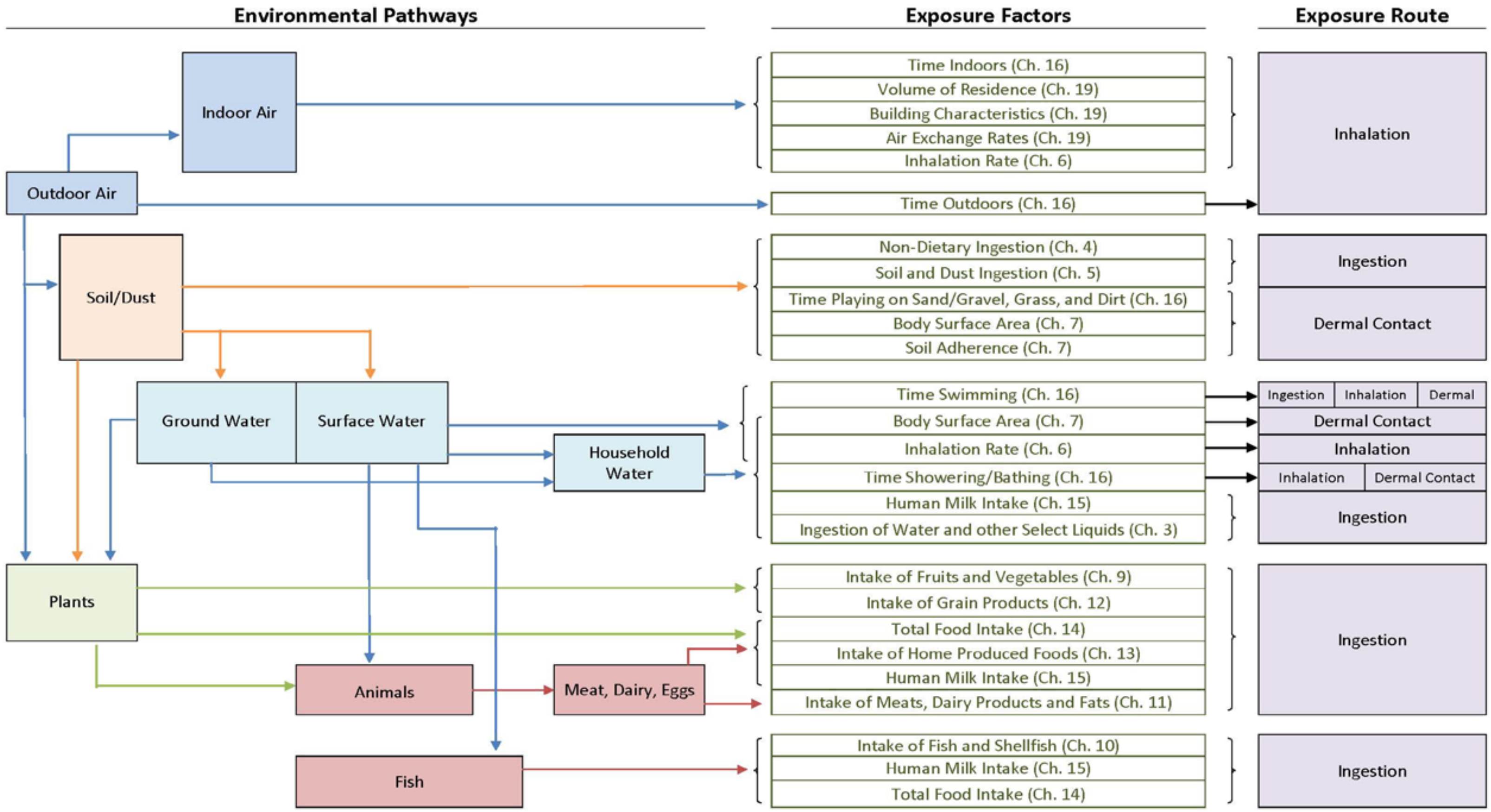


Figure 1-2. Exposure-Dose-Effect Continuum.

Source: Redrawn from U.S. EPA (2003c); WHO (2006); Ott (2007).

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

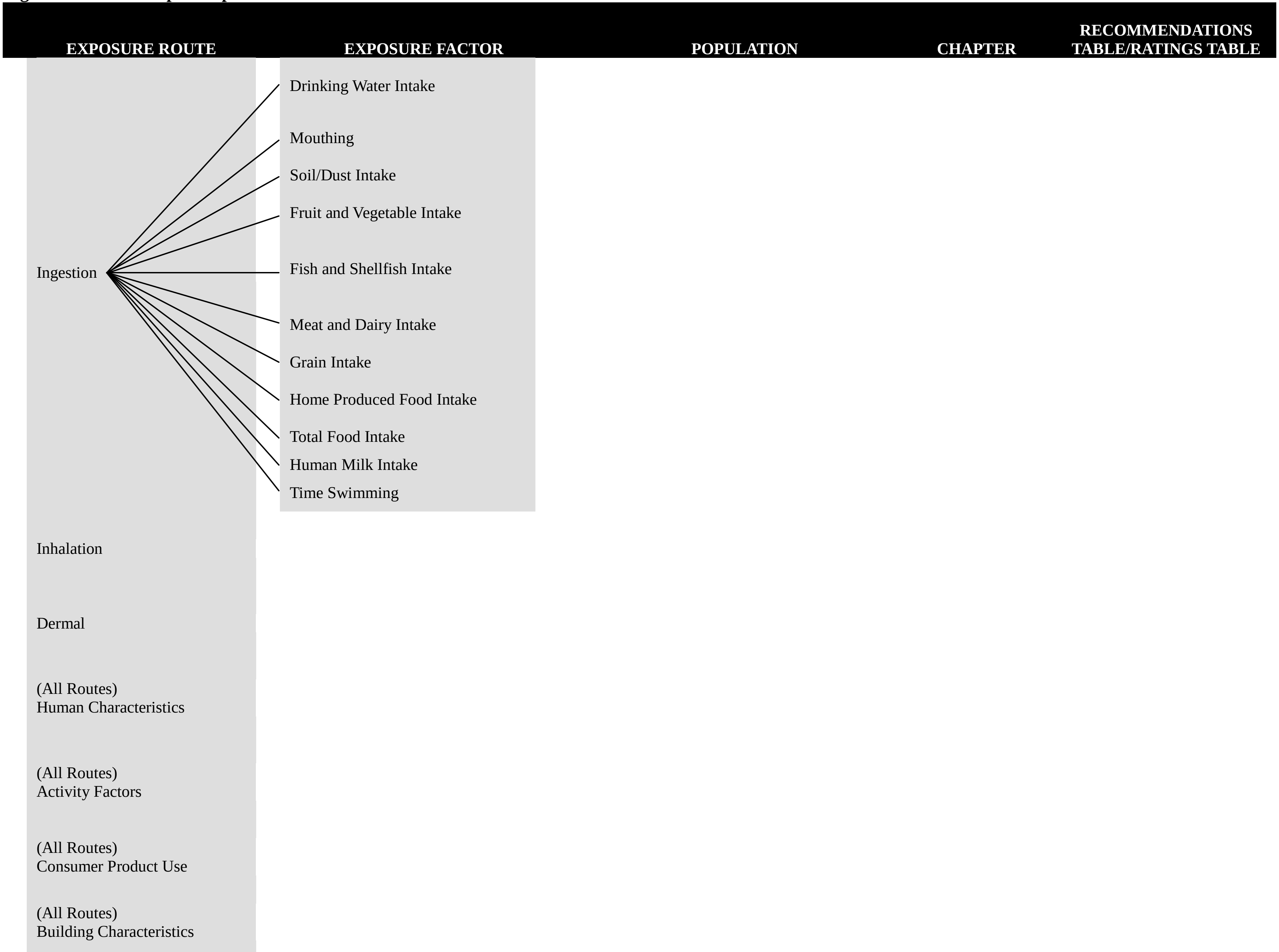


Notes:
The pathways presented are selected pathways. This diagram is not meant to be comprehensive.
Consumer Products (Ch. 17), such as perfume, are not shown on this diagram. Humans can be exposed to consumer products through all pathways and routes.
Body Weight (Ch. 8) and Lifetime (Ch. 18) potentially modify all exposure pathways.

Figure 1-3. Schematic Diagram of Exposure Pathways, Factors, and Routes.

EXPOSURE ROUTE	EXPOSURE FACTOR	POPULATION	CHAPTER	RECOMMENDATIONS TABLE/RATINGS TABLE
Ingestion				
Inhalation				
Dermal				
(All Routes) Human Characteristics				
(All Routes) Activity Factors				
(All Routes) Consumer Product Use				
(All Routes) Building Characteristics				

Figure 1-4. Road map to Exposure Factor Recommendations.



EXPOSURE ROUTE	EXPOSURE FACTOR	POPULATION	CHAPTER	RECOMMENDATIONS TABLE/RATINGS TABLE
Ingestion	Drinking Water Intake	Adults Children Pregnant Women	3	3-1 / 3-2 3-3 / 3-4
	Mouthing			
	Soil/Dust Intake			
	Fruit and Vegetable Intake			
	Fish and Shellfish Intake			
	Meat and Dairy Intake			
	Grain Intake			
	Home Produced Food Intake			
	Total Food Intake			
	Human Milk Intake			
	Time Swimming			
Inhalation				
Dermal				
(All Routes) Human Characteristics				
(All Routes) Activity Factors				
(All Routes) Consumer Product Use				
(All Routes) Building Characteristics				

EXPOSURE ROUTE	EXPOSURE FACTOR	POPULATION	CHAPTER	RECOMMENDATIONS TABLE/RATINGS TABLE
Ingestion	Drinking Water Intake			
	Mouthing	Frequency Duration	4	4-1 / 4-2
	Soil/Dust Intake			
	Fruit and Vegetable Intake			
	Fish and Shellfish Intake			
	Meat and Dairy Intake			
	Grain Intake			
	Home Produced Food Intake			
	Total Food Intake			
	Human Milk Intake			
	Time Swimming			
Inhalation				
Dermal				
(All Routes) Human Characteristics				
(All Routes) Activity Factors				
(All Routes) Consumer Product Use				
(All Routes) Building Characteristics		Commercial Buildings		19-3 / 19-4

EXPOSURE ROUTE	EXPOSURE FACTOR	POPULATION	CHAPTER	RECOMMENDATIONS TABLE/RATINGS TABLE
Ingestion	Drinking Water Intake			
	Mouthing			
	Soil/Dust Intake	Adults Children	5	5-1 / 5-2
	Fruit and Vegetable Intake			
	Fish and Shellfish Intake			
	Meat and Dairy Intake			
	Grain Intake			
	Home Produced Food Intake			
	Total Food Intake			
	Human Milk Intake			
	Time Swimming			
Inhalation				
Dermal				
(All Routes) Human Characteristics				
(All Routes) Activity Factors				
(All Routes) Consumer Product Use				
(All Routes) Building Characteristics				

EXPOSURE ROUTE	EXPOSURE FACTOR	POPULATION	CHAPTER	RECOMMENDATIONS TABLE/RATINGS TABLE
Ingestion	Drinking Water Intake			
	Mouthing			
	Soil/Dust Intake			
	Fruit and Vegetable Intake	Adults Children	9	9-1 / 9-2
	Fish and Shellfish Intake			
	Meat and Dairy Intake			
	Grain Intake			
	Home Produced Food Intake			
	Total Food Intake			
	Human Milk Intake			
	Time Swimming			
Inhalation				
Dermal				
(All Routes) Human Characteristics				
(All Routes) Activity Factors				
(All Routes) Consumer Product Use				
(All Routes) Building Characteristics				

EXPOSURE ROUTE	EXPOSURE FACTOR	POPULATION	CHAPTER	RECOMMENDATIONS TABLE/RATINGS TABLE
Ingestion	Drinking Water Intake			
	Mouthing			
	Soil/Dust Intake			
	Fruit and Vegetable Intake			
	Fish and Shellfish Intake	General Population	10	10-1 / 10-2
		Marine Recreational		10-3 / 10-4
		Freshwater Recreational		10-5
		Native American Populations		10-6
	Meat and Dairy Intake			
	Grain Intake			
	Home Produced Food Intake			
	Total Food Intake			
	Human Milk Intake			
	Time Swimming			
Inhalation				
Dermal				
(All Routes) Human Characteristics				
(All Routes) Activity Factors				
(All Routes) Consumer Product Use				
(All Routes) Building Characteristics				

EXPOSURE ROUTE	EXPOSURE FACTOR	POPULATION	CHAPTER	RECOMMENDATIONS TABLE/RATINGS TABLE
Ingestion	Drinking Water Intake			
	Mouthing			
	Soil/Dust Intake			
	Fruit and Vegetable Intake			
	Fish and Shellfish Intake			
	Meat and Dairy Intake	Adults Children	11	11-1 / 11-2
	Grain Intake			
	Home Produced Food Intake			
	Total Food Intake			
	Human Milk Intake			
	Time Swimming			
Inhalation				
Dermal				
(All Routes) Human Characteristics				
(All Routes) Activity Factors				
(All Routes) Consumer Product Use				
(All Routes) Building Characteristics				

EXPOSURE ROUTE	EXPOSURE FACTOR	POPULATION	CHAPTER	RECOMMENDATIONS TABLE/RATINGS TABLE
Ingestion	Drinking Water Intake			
	Mouthing			
	Soil/Dust Intake			
	Fruit and Vegetable Intake			
	Fish and Shellfish Intake			
	Meat and Dairy Intake			
	Grain Intake	Adults Children	12	12-1 / 12-2
	Home Produced Food Intake			
	Total Food Intake			
	Human Milk Intake			
	Time Swimming			
Inhalation				
Dermal				
(All Routes) Human Characteristics				
(All Routes) Activity Factors				
(All Routes) Consumer Product Use				
(All Routes) Building Characteristics				

EXPOSURE ROUTE	EXPOSURE FACTOR	POPULATION	CHAPTER	RECOMMENDATIONS TABLE/RATINGS TABLE
Ingestion	Drinking Water Intake			
	Mouthing			
	Soil/Dust Intake			
	Fruit and Vegetable Intake			
	Fish and Shellfish Intake			
	Meat and Dairy Intake			
	Grain Intake			
	Home Produced Food Intake	Adults Children	13	13-1 / 13-2
	Total Food Intake			
	Human Milk Intake			
	Time Swimming			
Inhalation				
Dermal				
(All Routes) Human Characteristics				
(All Routes) Activity Factors				
(All Routes) Consumer Product Use				
(All Routes) Building Characteristics				

EXPOSURE ROUTE	EXPOSURE FACTOR	POPULATION	CHAPTER	RECOMMENDATIONS TABLE/RATINGS TABLE
Ingestion	Drinking Water Intake			
	Mouthing			
	Soil/Dust Intake			
	Fruit and Vegetable Intake			
	Fish and Shellfish Intake			
	Meat and Dairy Intake			
	Grain Intake			
	Home Produced Food Intake			
	Total Food Intake	Adults Children	14	14-1 / 14-2
	Human Milk Intake			
	Time Swimming			
Inhalation				
Dermal				
(All Routes) Human Characteristics				
(All Routes) Activity Factors				
(All Routes) Consumer Product Use				
(All Routes) Building Characteristics				

EXPOSURE ROUTE	EXPOSURE FACTOR	POPULATION	CHAPTER	RECOMMENDATIONS TABLE/RATINGS TABLE
Ingestion	Drinking Water Intake			
	Mouthing			
	Soil/Dust Intake			
	Fruit and Vegetable Intake			
	Fish and Shellfish Intake			
	Meat and Dairy Intake			
	Grain Intake			
	Home Produced Food Intake			
	Total Food Intake			
	Human Milk Intake	Exclusively Breastfed Infants	15	15-1 / 15-2
	Time Swimming			
Inhalation				
Dermal				
(All Routes) Human Characteristics				
(All Routes) Activity Factors				
(All Routes) Consumer Product Use				
(All Routes) Building Characteristics				

EXPOSURE ROUTE	EXPOSURE FACTOR	POPULATION	CHAPTER	RECOMMENDATIONS TABLE/RATINGS TABLE
Ingestion	Drinking Water Intake			
	Mouthing			
	Soil/Dust Intake			
	Fruit and Vegetable Intake			
	Fish and Shellfish Intake			
	Meat and Dairy Intake			
	Grain Intake			
	Home Produced Food Intake			
	Total Food Intake			
	Human Milk Intake			
	Time Swimming	Adults Children	16	16-1 / 16-2
Inhalation				
Dermal				
(All Routes) Human Characteristics				
(All Routes) Activity Factors				
(All Routes) Consumer Product Use				
(All Routes) Building Characteristics				

EXPOSURE ROUTE	EXPOSURE FACTOR		POPULATION	CHAPTER	RECOMMENDATIONS TABLE/RATINGS TABLE
Ingestion					
Inhalation	Inhalation Rate	Long Term	Adults Children	6	6-1 / 6-3
		Short Term	Adults Children		6-2 / 6-3
Dermal					
(All Routes) Human Characteristics					
(All Routes) Activity Factors					
(All Routes) Consumer Product Use					
(All Routes) Building Characteristics					

EXPOSURE ROUTE	EXPOSURE FACTOR	POPULATION	CHAPTER	RECOMMENDATIONS TABLE/RATINGS TABLE
Ingestion				
Inhalation				
Dermal	Body Surface Area	Adults Children	7	7-1, 7-2 / 7-3
	Adherence of Solids	Adults Children		7-4 / 7-5
(All Routes) Human Characteristics				
(All Routes) Activity Factors				
(All Routes) Consumer Product Use				
(All Routes) Building Characteristics				

EXPOSURE ROUTE	EXPOSURE FACTOR	POPULATION	CHAPTER	RECOMMENDATIONS TABLE/RATINGS TABLE
Ingestion				
Inhalation				
Dermal				
(All Routes) Human Characteristics	Body Weight	Adults Children	8	8-1 / 8-2
	Lifetime			
(All Routes) Activity Factors				
(All Routes) Consumer Product Use				
(All Routes) Building Characteristics				

EXPOSURE ROUTE	EXPOSURE FACTOR	POPULATION	CHAPTER	RECOMMENDATIONS TABLE/RATINGS TABLE
Ingestion				
Inhalation				
Dermal				
(All Routes) Human Characteristics	Body Weight			
	Lifetime	Males Females	18	18-1 / 18-2
(All Routes) Activity Factors				
(All Routes) Consumer Product Use				
(All Routes) Building Characteristics				

EXPOSURE ROUTE	EXPOSURE FACTOR	POPULATION	CHAPTER	RECOMMENDATIONS TABLE/RATINGS TABLE
Ingestion				
Inhalation				
Dermal				
(All Routes) Human Characteristics				
(All Routes) Activity Factors	Activity Patterns	Adults Children	16	16-1 / 16-2
	Occupational Mobility	Adults		16-3 / 16-4
	Population Mobility	Adults Children		16-5 / 16-6
(All Routes) Consumer Product Use				
(All Routes) Building Characteristics				

EXPOSURE ROUTE	EXPOSURE FACTOR	POPULATION	CHAPTER	RECOMMENDATIONS TABLE/RATINGS TABLE
Ingestion				
Inhalation				
Dermal				
(All Routes) Human Characteristics				
(All Routes) Activity Factors				
(All Routes) Consumer Product Use	Frequency of Use Amount Used Duration	General Population	17	No Recommendations
(All Routes) Building Characteristics				

EXPOSURE ROUTE	EXPOSURE FACTOR	POPULATION	CHAPTER	RECOMMENDATIONS TABLE/RATINGS TABLE
Ingestion				
Inhalation				
Dermal				
(All Routes) Human Characteristics				
(All Routes) Activity Factors				
(All Routes) Consumer Product Use				
(All Routes) Building Characteristics	Air Exchange Rates	Residential Buildings	19	19-1 / 19-2
		Commercial Buildings		19-3 / 19-4
	Building Volume	Residential Buildings		19-1 / 19-2
		Commercial Buildings		19-3 / 19-4

APPENDIX 1A

RISK CALCULATIONS USING EXPOSURE FACTORS HANDBOOK DATA AND DOSE-RESPONSE INFORMATION FROM THE INTEGRATED RISK INFORMATION SYSTEM (IRIS)

APPENDIX 1A—RISK CALCULATIONS USING EXPOSURE FACTORS HANDBOOK DATA AND DOSE-RESPONSE INFORMATION FROM THE INTEGRATED RISK INFORMATION SYSTEM (IRIS)

1A-1. INTRODUCTION

When estimating risk to a specific population from chemical exposure, whether it is the entire national population or some smaller population of interest, exposure data (either from this handbook or from other sources) must be combined with dose-response information. The dose-response information typically comes from the Integrated Risk Information System (IRIS) database, which maintains a list of toxicity (i.e., dose-response) values for a number of chemical agents (www.epa.gov/iris). Care must be taken to ensure that population parameters from the dose-response assessment are consistent with the population parameters used in the exposure analysis. This appendix discusses procedures for ensuring this consistency.

The U.S. EPA's approach to estimating risks associated with toxicity from non-cancer effects is fundamentally different from its approach to estimating risks associated with toxicity from carcinogenic effects. One difference is that different assumptions are made regarding the mode of action that is involved in the generation of these two types of effects. For non-cancer effects, the Agency assumes that these effects are produced through a non-linear (e.g., “threshold”) mode of action (i.e., there exists a dose below which effects do not occur) (U.S. EPA, 1993). For carcinogenic effects, deemed to operate through a mutagenic mode of action or for which the mode of action is unknown, the Agency assumes there is the absence of a “threshold” (i.e., there exists no level of exposure that does not pose a small, but finite, probability of generating a carcinogenic response).

For carcinogens, quantitative estimates of risks for the oral route of exposure are generated using cancer slope factors. The cancer slope factor is an upper bound estimate of the increase in cancer risk per unit of dose and is typically expressed in units of (mg/kg-day)$^{-1}$. Because dose-response assessment typically involves extrapolating from laboratory animals to humans, a human equivalent dose (HED) is calculated from the animal data in order to derive a cancer slope factor that is appropriately expressed in human equivalents. The Agency endorses a hierarchy of approaches to derive human equivalent oral exposures from data in laboratory animal species, with the preferred approach being physiologically based toxicokinetic (PBTK) modeling. In the absence of PBTK modeling, U.S. EPA advocates using body weight to the ¾ power ($BW^{3/4}$) as the default scaling factor for extrapolating toxicologically equivalent doses of orally administered agents from animals to humans (U.S. EPA, 2011).

Application of the $BW^{3/4}$ scaling factor is based on adult animal and human body weights to adjust for dosimetric differences (predominantly toxicokinetic) between adult animals and humans (U.S. EPA, 2011). The internal dosimetry of other life stages (e.g., children, pregnant or lactating mothers) may be different from that of an adult (U.S. EPA, 2011). In some cases where data are available on effects in infants or children, adult PBTK models (if available) could be parameterized in order to predict the dose metric in children, as described in U.S. EPA’s report, *A Framework for Assessing Health Risk of Environmental Exposures to Children* (U.S. EPA, 2011, 2006b). However, more research is needed to develop models for children’s dosimetric adjustments across life stages and experimental animal species (U.S. EPA, 2006b).

In Summary:

- *No correction factors are applied to RfDs and RfCs when combined with exposure information from specific populations of interest.*
- *ADAFs are applied to oral slope factors, drinking water unit risks, and inhalation unit risks for chemicals with a mutagenic mode of action as in Table 1A-1.*
- *Correction factors are applied to water unit risks for both body weight and water intake rate for specific populations of interest.*

For cancer data from chronic animal studies, no explicit lifetime adjustment is necessary when extrapolating to humans because the assumption is that events occurring in a lifetime animal bioassay will occur with equal probability in a human lifetime. For cancer data from human studies (either occupational or general population), the Agency typically makes no explicit assumptions regarding body weight or human lifetime. For both of these parameters, there is an implicit assumption that the exposed population of interest has the same characteristics as the population analyzed by the Agency in deriving its dose-response information. In the rare situation where this assumption is known to be violated, the Agency has made appropriate corrections so that the dose-response parameters are representative of the national average population.

For carcinogens acting through a mutagenic MOA, where chemical-specific data concerning early life susceptibility are lacking, early life susceptibility should be assumed, and the following ADAFs should be applied to the oral cancer slope factor, drinking water unit risks, and inhalation unit risks as described in the *Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens* (U.S. EPA, 2005e) and summarized in Section 1.9 of this handbook:

- 10-fold for exposures occurring before 2 years of age;
- 3-fold for exposures occurring between the ages of 2 and 16 years of age; and
- no adjustment for exposures occurring after 16 years of age.

In addition to cancer slope factors, dose-response measures for carcinogens are also expressed as increased cancer risk per unit concentration for estimating risks from exposure to substances found in air or water (U.S. EPA, 1992b). For exposure via inhalation, this dose-response value is referred to as an IUR and is typically expressed in units of $(\mu g/m^3)^{-1}$. For exposure via drinking water, this dose-response value is termed the drinking water unit risk (U.S. EPA, 1992b). These unit risk estimates implicitly assume standard adult intake rates (i.e., 2 L/day of drinking water; 20-m^3/day inhalation rate). It is generally not appropriate to adjust the inhalation unit risk for different body weights or inhalation rates because the amount of chemical that reaches the target site is not a simple function of two parameters (U.S. EPA, 2009b). For drinking water unit risks, however, it would be appropriate for risk assessors to replace the standard intake rates with values representative of the exposed population of interest, as described in Section 1A-2 and Table 1A-1 below (U.S. EPA, 2005e).

As indicated above, for non-cancer effects, dose-response assessment is based on a threshold hypothesis, which holds that there is a dose above which effects (or their precursors) begin to occur. The U.S. EPA defines the RfD as "an estimate of a daily oral exposure for a given duration to the human population (including susceptible subgroups) that is likely to be without an appreciable risk of adverse health effects over a lifetime. It is derived from a benchmark dose lower confidence limit (BMDL), a no-observed-adverse-effect level, a lowest-observed-adverse-effect level, or another suitable point of departure, with uncertainty/variability factors applied to reflect limitations of the data used." The point of departure on which the RfD is based can come directly from animal dosing experiments or occasionally from human studies followed by application of uncertainty factors to reflect uncertainties such as extrapolating from subchronic to chronic exposure, extrapolating from animals to humans, and deficiencies in the toxicity database. Consistent with the derivation of oral cancer slope factors noted above, the U.S. EPA prefers the use of PBTK modeling to derive HEDs to extrapolate from data in laboratory animal species, but in the absence of a PBTK model, endorses the use of $BW^{3/4}$ as the appropriate default scaling factor for use in calculating HEDs for use in derivation of the oral RfD (U.S. EPA, 2011). Body-weight scaling using children's body weight may not be appropriate in the derivation of the RfD because RfDs are already intended to be protective of the entire population including susceptible populations such as children and other life stages (U.S. EPA, 2011). Uncertainty factors are used to account for intraspecies variation in susceptibility (U.S. EPA, 2011). As indicated above, body-weight scaling is meant to predominantly address toxicokinetic differences between animals and humans and can be viewed as a dosimetric adjustment factor (DAF). Data on toxicodynamic processes needed to assess the appropriateness of body-weight scaling for early life stages are not currently available (U.S. EPA, 2011).

The procedure for deriving dose-response values for non-cancer effects resulting from the inhalation route of exposure (i.e., RfCs) differs from the procedure used for deriving dose-response values for non-cancer effects resulting from the oral route of exposure (i.e., RfDs). The difference lies primarily in the source of the DAFs that are employed. As with the RfD, the U.S. EPA prefers the application of PBTK modeling in order to extrapolate laboratory animal exposure concentrations to HECs for the derivation of an RfC. In the absence of a PBTK model, the U.S. EPA advocates the use of a default procedure for deriving HECs that involve application of DAFs. This procedure uses species-specific physiologic and anatomic factors relevant to the physical form of the pollutant (i.e., particulate or gas) and categorizes the pollutant with regard to whether it elicits a response either locally (i.e., within the respiratory tract) or remotely (i.e., extrarespiratory). These factors are combined in determining an appropriate DAF. The default dosimetric adjustments and physiological parameters used in RfC derivations assume an adult male with an air intake rate of 20 m^3/day and a body weight of 70 kg (U.S. EPA, 1994). Assumptions for extrathoracic, tracheobronchial, and pulmonary surface areas are also made based on an adult male (U.S. EPA, 1994). For gases, the parameters needed for deriving a DAF include species-to-species ratios of blood:gas partition coefficients. For particulates, the DAF is termed the regional deposition dose ratio and is derived from parameters that include region-specific surface areas, the ratio of animal-to-human minute volumes, and the ratio of animal-to-human regional fractional deposition. If DAFs are not available, simple ventilation rate adjustments can be made in generating HECs for use in derivation of the RfC (U.S. EPA, 2006b). Toxicity values (RfCs) derived using the default approach from the inhalation dosimetry methodology described in U.S. EPA (1994) are developed for the human population as a whole, including sensitive groups. Therefore, no quantitative adjustments of these toxicity values are needed to account for different ventilation rates or body weights of specific age groups (U.S. EPA, 2009b).

1A-2. CORRECTIONS FOR DOSE-RESPONSE PARAMETERS

The correction factors for the dose-response values tabulated in the IRIS database for non-cancer and carcinogenic effects are summarized in Table 1A-1. Use of these correction factors is necessary to avoid introducing errors into the risk analysis. This table is applicable in most cases that will be encountered, but it is not applicable when (a) the effective dose has been derived with a PBTK model, and (b) the dose-response data have been derived from human data. In the former case, the population parameters need to be incorporated into the model. In the latter case, the correction factor for the dose-response parameter must be evaluated on a case-by case basis by examining the specific data and assumptions employed in the derivation of the parameter.

It is important to note that the 2 L/day per capita water intake assumption is closer to a 90th percentile intake value than an average value. If an average measure of exposure in adults is of interest, the drinking water unit risk can be adjusted by multiplying it by 1.0/2 or 0.5, where 1.0 L/day is the average per capita water intake for adults ≥21 years old (see Chapter 3 of this handbook). If the population of interest is children, rather than adults, then a body-weight adjustment is also necessary. For example, the average water intake for children 3 to <6 years of age is 0.33 L/day (see Chapter 3 of this handbook), and the average body weight in this age group is 18.6 kg (see Chapter 8 of this handbook). The water unit risk then needs to be adjusted by multiplying it by an adjustment factor derived from these age-group-specific values and calculated using the formula from Table 1A-1 as follows:

Water unit risk correction factor =

$$\left[\frac{0.33(L/day)}{2(L/day)}\right]\times\left[\frac{70(kg)}{18.6(kg)}\right]=0.6 \quad \text{(Eqn. 1A-1)}$$

1A-3. REFERENCES FOR APPENDIX 1A

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U.S. EPA (U.S. Environmental Protection Agency). (2011). Recommended use of body weight 3/4 as the default method in derivation of the oral reference dose. (EPA/100/R11/0001). Washington, DC. http://www.epa.gov/raf/publications/interspecies-extrapolation.htm.

Table 1A-1. Procedures for Modifying IRIS Risk Values for Non-Standard Populations	
IRIS Risk Measure [Units]	Correction Factor (CF) for Modifying IRIS Risk Measures[a]
RfD	No correction factor needed
RfC	No correction factor needed
Oral Slope Factor $[\text{mg/(kg-day)}]^{-1}$	No correction factor needed except for chemicals with mutagenic MOA. ADAFs are applied as follows: • 10-fold for exposure occurring before 2 years of age • 3-fold for exposure occurring between the ages of 2 and 16 • no adjustment for exposures occurring after 16 years of age
Drinking Water Unit Risk $[\mu\text{g/L}]^{-1}$	$[I_W^P/2] \times [70/(W^P)]$ For chemicals with mutagenic MOA, ADAFs are applied as follows: • 10-fold for exposure occurring before 2 years of age • 3-fold for exposure occurring between the ages of 2 and 16 • no adjustment for exposures occurring after 16 years of age
Inhalation Unit Risk $[\mu\text{g/m}^3]^{-1}$	No correction factor needed except for chemicals with mutagenic MOA. ADAFs are applied as follows: • 10-fold for exposure occurring before 2 years of age • 3-fold for exposure occurring between the ages of 2 and 16 • no adjustment for exposures occurring after 16 years of age

[a] Modified risk measure = (CF) × IRIS value.
W = Body weight (kg)
I_W = Drinking water intake (liters per day)
W^P, I_W^P = Denote non-standard parameters from the actual population of interest

2. VARIABILITY AND UNCERTAINTY

Accounting for variability and uncertainty is fundamental to exposure assessment and risk analysis. While more will be said about the distinction between variability and uncertainty in Section 2.1, it is useful at this point to motivate the treatment of variability and uncertainty in exposure assessment. Given that exposure and susceptibility to exposure is usually not uniform across a population, accounting for variability is the means by which a risk assessor properly accounts for risk to the population as a whole. However, a risk assessment usually involves uncertainties about the precision of a risk estimate. A heuristic distinction between variability and uncertainty is to consider uncertainty as a lack of knowledge about factors affecting exposure or risk, whereas variability arises from heterogeneity across people, places, or time.

Properly addressing variability and uncertainty will increase the likelihood that results of an assessment or analysis will be used in an appropriate manner. Characterizing and communicating variability and uncertainty should be done throughout all the components of the risk assessment process (NRC, 1994). Thus, careful consideration of the variability and uncertainty associated with the exposure factors information used in an exposure assessment is of utmost importance. Proper characterization of variability and uncertainty will also support effective communication of risk estimates to risk managers and the public.

This chapter provides an overview of variability and uncertainty in the context of exposure analysis and is not intended to present specific methodological guidance. It is intended to acquaint the exposure assessor with some of the fundamental concepts of variability and uncertainty as they relate to exposure assessment and the exposure factors presented in this handbook. It also provides summary descriptions of methods and considerations for evaluating and presenting the uncertainty associated with exposure estimates and a bibliography of references on a wide range of methodologies concerned with the application of variability and uncertainty analysis in exposure assessment. Subsequent sections in this chapter are devoted to the following topics:

2.1 Variability versus uncertainty;
2.2 Types of variability;
2.3 Addressing variability;
2.4 Types of uncertainty;
2.5 Reducing uncertainty;
2.6 Analyzing variability and uncertainty;
2.7 Literature review of variability and uncertainty analysis;
2.8 Presenting results of variability and uncertainty analyses; and
2.9 References.

There are numerous ongoing efforts in the U.S. Environmental Protection Agency (EPA) and elsewhere to further improve the characterization of variability and uncertainty. The U.S. EPA's Risk Assessment Forum has established guidelines for the use of probabilistic techniques (e.g., Monte Carlo analysis) to better assess and communicate risk (U.S. EPA, 1997a, b). The U.S. EPA's Science Policy Council is developing white papers on the use of expert elicitation for characterizing uncertainty in risk assessments. Expert judgment has been used in the past by some regulatory agencies when limited data or knowledge results in large uncertainties (NRC, 2009). The International Program on Chemical Safety (IPCS) has developed guidance on characterizing and communicating uncertainty in exposure assessment (WHO, 2008). Suggestions for further reading on variability and uncertainty include Babendreier and Castleton (2005), U.S. EPA (2008), Saltelli and Annoni (2010), Bogen et al. (2009), and Refsgaard et al. (2007).

2.1. VARIABILITY VERSUS UNCERTAINTY

While some authors have treated variability as a specific type or component of uncertainty, the U.S. EPA (1995), following the NRC (1994) recommendation, has advised the risk assessor to distinguish between variability and uncertainty. Variability is a quantitative description of the range or spread of a set of values. Common measures include variance, standard deviation, and interquartile range. Variability arises from heterogeneity across individuals, places, or time. Uncertainty can be defined as a lack of precise knowledge, either qualitative or quantitative. In the context of exposure assessment, data uncertainty refers to the lack of knowledge about factors affecting exposure.

The key difference between uncertainty and variability is that variability cannot be reduced, only better characterized (NRC, 2009).

We will describe a brief example of human water consumption in relation to lead poisoning to help distinguish between variability and parameter uncertainty (a particular type of uncertainty). We might characterize the variability of water consumption across individuals by sampling from a population and measuring water consumption. From this sample, we obtain useful statistics on the variability of water consumption, which we assume here represents the population of interest. There may be similar statistics on the variability in the concentration of lead in the water consumed. A risk model may include a factor (i.e., dose response, representing the absorption of lead from ingested water to blood). The dose response may be represented by a constant in a risk model. However, knowledge about the dose response may be uncertain, motivating an uncertainty analysis. Dose response values are often relatively uncertain compared to exposure parameters. Therefore, in the above example, a high uncertainty surrounds the absorption of lead, whereas there is less uncertainty associated with the parameters of water consumption (i.e., population mean and standard deviation). One challenge in modeling dose-response uncertainty is the lack of consensus on its treatment.

Most of the data presented in this handbook concern variability. Factors contributing to variability in risk include variability in exposure potential (e.g., differing behavioral patterns, location), variability in susceptibility due to endogenous factors (e.g., age, sex, genetics, pre-existing disease), variability in susceptibility due to exogenous factors (e.g., exposures to other agents) (NRC, 2009).

2.2. TYPES OF VARIABILITY

Variability in exposure is dependent on contaminant concentrations as well as variability in human exposure factors. Human exposure factors may vary because of an individual's location, specific exposure time, or behavior. However, even if all of those factors were constant across a set of individuals, there could still be variability in risk because of variability in susceptibilities. Variations in contaminant concentrations and human exposure factors are not necessarily independent. For example, contaminant concentrations and behavior might be correlated.

A useful way to think about sources of variability is to consider these four broad categories:

1) Spatial variability: variability across locations;
2) Temporal variability: variability over time;
3) Intra-individual variability: variability within an individual; and
4) Inter-individual variability: variability across individuals.

Spatial variability refers to differences that may occur because of location. For example, outdoor pollutant levels can be affected at the regional level by industrial activities and at the local level by activities of individuals. In general, higher exposures tend to be associated with closer proximity to a pollutant source, whether it is an industrial plant or related to a personal activity such as showering or gardening. Susceptibilities may vary across locations, for example, some areas have particularly high concentrations of a younger or older population.

Temporal variability refers to variations over time, whether long- or short-term. Different seasons may cause varied exposure to pesticides, bacteria, or indoor air pollution, each of which might be considered an example of long-term variability. Examples of short-term variability are differences in industrial or personal activities on weekdays versus weekends or at different times of the day.

Intra-individual variability is a function of fluctuations in an individual's physiologic (e.g., body weight), or behavioral characteristics (e.g., ingestion rates or activity patterns). For example, patterns of food intake change from day to day and may do so significantly over a lifetime. Intra-individual variability may be associated with spatial or temporal variability. For example, because an individual's dietary intake may reflect local food sources, intake patterns may change if place of residence changes. Also, physical activity may vary depending upon the season, life stage, or other factors associated with temporal variability.

Inter-individual variability refers to variation across individuals. Three broad categories include the following:

1) individual characteristics such as sex, age, race, height, or body weight (including any obesity), phenotypic genetic expression, and pathophysiological conditions;
2) individual behaviors such as activity patterns, and ingestion rates; and
3) susceptibilities due to such things as life stage or genetic predispositions.

Inter-individual variability may also be related to spatial and temporal factors.

2.3. ADDRESSING VARIABILITY

In this handbook, variability is addressed by presenting data on the exposure factors in one of the following three ways: (1) as tables with percentiles or ranges of values for various age groups or other populations, (2) as probability distributions with specified parameter estimates and related confidence intervals, or (3) as a qualitative discussion. One approach to exposure assessment is to assume a single value for a given exposure level, often the mean or median, in order to calculate a single point estimate of risk. Often however, individuals vary in their exposure, and an exposure assessment would be remiss to exclude other possible exposure levels. Thus, an exposure assessment often involves a quantification of the exposure at high levels of the exposure factor, i.e., 90^{th}, 95^{th}, and 99^{th} percentiles, and not only the mean or median exposure. Where possible, confidence limits for estimated percentiles should be provided. The U.S. EPA's approach to variability assessment is described in *Risk Assessment Principles and Practices: Staff Paper* (U.S. EPA, 2004b). Accounting for variability in an exposure assessment may be limited to a deterministic model in which high-end values are used or may involve a probabilistic approach, e.g., Monte Carlo Analysis (U.S. EPA, 1997a).

Populations are by nature heterogeneous. Characterizing the variability in the population can assist in focusing analysis on segments of the population that may be at higher risk from environmental exposure. Although population variability cannot be reduced, data variability can be lessened by disaggregating the population into segments with similar characteristics.

Although much of this handbook is concerned with variability in exposure, it is critical to note that there are also important variations among individuals in a population with respect to susceptibility. As noted in NRC (2009), people differ in susceptibility to the toxic effects of a given chemical exposure because of such factors as genetics, lifestyle, predisposition to diseases and other medical conditions, and other chemical exposures that influence underlying toxic processes. Susceptibility is also a function of life stages, e.g., children may be at risk of high exposure relative to adults. Susceptibility factors are broadly considered to include any factor that increases (or decreases) the response of an individual to a dose relative to a typical individual in the population. The distribution of disease in a population can result not only from differences in susceptibility, but from differing exposures of individuals and target groups in a population. Taken together, variations in disease susceptibility and exposure potential give rise to potentially important variations in vulnerability to the effects of environmental chemicals (NRC, 2009).

2.4. TYPES OF UNCERTAINTY

Uncertainty in exposure analysis is related to the lack of knowledge concerning one or more components of the assessment process. The U.S. EPA (1992) has classified uncertainty in exposure assessment into three broad categories: (1) scenario uncertainty, (2) parameter uncertainty, and (3) model uncertainty.

Scenario uncertainty

Scenario uncertainty arises from descriptive errors, aggregation errors, errors in professional judgment, and incomplete analysis. Descriptive errors are errors in information that translate into errors in the development of exposure pathways, scenarios, exposed population, and exposure estimates. Aggregation errors occur as a result of lumping approximations. These include, for example, assuming a homogeneous population, and spatial and temporal assumptions. Uncertainty can also arise from errors in professional judgment. These errors affect how an exposure scenario is defined, the selection of exposure parameters, exposure routes and pathways, populations of concern, chemicals of concern, and the selection of appropriate models. An incomplete analysis can also be a source of uncertainty because important exposure scenarios and susceptible populations may be overlooked.

Parameter uncertainty

Risk assessments depict reality interpreted through mathematical representations that describe major processes and relationships. Process or mechanistic models use equations to describe the processes that an environmental agent undergoes in the environment in traveling from the source to the target organism. Mechanistic models have also been developed to represent the toxicokinetic and toxicodynamic processes that take place inside the organism, leading to the toxic endpoint. The specific parameters of the equations found in these models are factors that influence the release, transport, and transformation of the environmental agent, the exposure of the target organism to the agent, transport and metabolism of the agent in the body, and interactions on the cellular and molecular levels. Empirical models are also used to define relationships between two values, such as the dose and the response. Uncertainty in parameter estimates stem from a variety of sources, including the following:

a. Measurement errors:
   1. Random errors in analytical devices (e.g., imprecision of continuous monitors that measure stack emissions).
   2. Systemic bias (e.g., estimating inhalation from indoor ambient air without considering the effect of volatilization of contaminants from hot water during showers).
b. Use of surrogate data for a parameter instead of direct analysis of it (e.g., use of standard emission factors for industrialized processes).
c. Misclassification (e.g., incorrect assignment of exposures of subjects in historical epidemiologic studies due to faulty or ambiguous information).
d. Random sampling error (e.g., variation in estimates due to who was randomly selected).
e. Non-representativeness with regard to specified criteria (e.g., developing emission factors for dry cleaners based on a sample of "dirty" plants that do not represent the overall population of plants).

Model uncertainty

Model uncertainties arise because of gaps in the scientific theory that is required to make predictions on the basis of causal inferences. Common types of model uncertainties in various risk assessment-related activities include the following:

a. Relationship errors (e.g., incorrectly inferring the basis of correlations between chemical structure and biological activity).
b. Oversimplified representations of reality (e.g., representing a three-dimensional aquifer with a two-dimensional mathematical model).
c. Incompleteness, i.e., exclusion of one or more relevant variables (e.g., relating asbestos to lung cancer without considering the effect of smoking on both those exposed to asbestos and those unexposed).
d. Use of surrogate variables for ones that cannot be measured (e.g., using wind speed at the nearest airport as a proxy for wind speed at the facility site).
e. Failure to account for correlations that cause seemingly unrelated events to occur more frequently than expected by chance (e.g., two separate components of a nuclear plant are both missing a particular washer because the same newly hired assembler put them together).
f. Extent of (dis)aggregation used in the model (e.g., whether to break up the fat compartment into subcutaneous and abdominal fat in a physiologically based pharmacokinetic, or PBPK, model).

Although difficult to quantify, model uncertainty is inherent in risk assessment that seeks to capture the complex processes impacting release, environmental fate and transport, exposure, and exposure response.

2.5. REDUCING UNCERTAINTY

Identification of the sources of uncertainty in an exposure assessment is the first step in determining how to reduce uncertainty. Because uncertainty in exposure assessments is fundamentally tied to a lack of knowledge concerning important exposure factors, strategies for reducing uncertainty often involve the application of more resources to gather either more or targeted data. Example strategies to reduce uncertainty include (1) collecting new data, (2) implementing an unbiased sample design, (3) identifying a more direct measurement method or a more appropriate target population, (4) using models to estimate missing values, (5) using surrogate data, (6) using default assumptions, (7) narrowing the scope of the assessment, and (8) obtaining expert elicitation. The best strategy likely depends on a combination of resource availability, time constraints, and the degree of confidence necessary in the results.

2.6. ANALYZING VARIABILITY AND UNCERTAINTY

There are different strategies available for addressing variability and uncertainty that vary in their level of sophistication. The level of effort required to conduct the analysis needs to be balanced against the need for transparency and timeliness.

Exposure assessments are often developed in a tiered approach. The initial tier usually screens out the exposure scenarios or pathways that are not expected to pose much risk, to eliminate them from more detailed, resource-intensive review. Screening-level assessments typically examine exposures on the high end of the expected exposure distribution. Because screening-level analyses usually are included in the final exposure assessment, it may contain scenarios that differ in sophistication, data quality, and amenability to quantitative expressions of variability or uncertainty. Several approaches can be used to analyze uncertainty in parameter values. When uncertainty is high, for example, an assessor may set order-of-magnitude bounding estimates of parameter ranges (e.g., from 0.1 to 10 liters for daily water intake). Another method may involve setting a range for each parameter as well as point estimates for certain parameters determined by available data or professional judgment.

A sensitivity analysis can be used to determine which parameters and exposures have the most impact on an exposure assessment. General concepts in sensitivity analysis are described in Saltelli et al. (2008). The International Program on Chemical Safety proposes a four-tier approach for addressing uncertainty and variability (WHO, 2006). The four tiers are similar to those proposed in U.S. EPA (1992) and include the use of default assumptions; a qualitative, systematic identification and characterization of uncertainty; a qualitative evaluation of uncertainty using bounding estimates, interval analysis, and sensitivity analysis; and a more sophisticated one- or two-stage probabilistic analysis (WHO, 2006).

Practical considerations regarding an uncertainty analysis include whether uncertainty would affect the results in a non-trivial way; an issue might be addressed by an initial sensitivity analysis in which a range of values are explored. An initial analysis of this sort might be facilitated by use of Microsoft Excel. Probabilistic risk analysis techniques are becoming more widely applied and are increasing in the level of sophistication. Bedford and Cooke (2001) describe in more detail the main tools and modeling techniques available for probabilistic risk analysis (Bedford and Cooke, 2001). If a probabilistic approach is pursued, another consideration is the choice of a software package. Popular software packages for Monte Carlo analysis range from the more general: Fortran, Mathematica, R, and SAS to the more specific: Crystal Ball, @Risk (Palisade Corporation), RISKMAN (PLG Inc.), and SimLab (Saltelli et al., 2004).

Increasingly, probabilistic methods are being utilized to analyze variability and uncertainty independently as well as simultaneously. It is sometimes challenging to distinguish between variability and parameter uncertainty in this context as both can involve the distributions of a random variable. For instance, parameter uncertainty can be estimated by the standard error of a random variable (itself a function of variability). Note that in this case, increasing the sample size necessarily reduces the parameter uncertainty (i.e., standard error).

More sophisticated techniques that attempt to simultaneously model both variability and uncertainty by sampling from their respective probability distributions are known as two-stage probabilistic analysis, or two-stage Monte Carlo analysis, which is discussed in great detail in Bogen and Spear (1987), Bogen (1990), Chapter 11 and Appendix I-3 of NRC (1994), and U.S. EPA (2001). These methods assume a probabilistic distribution for certain specified parameters. Random samples are drawn from each probabilistic distribution in a simulation and are used as input into a deterministic model. Analysis of the results from the simulations characterizes either the variability or uncertainty (or both) of the exposure assessment.

Through the implementation of computationally efficient Markov Chain Monte Carlo algorithms like Metropolis-Hastings, Bayesian methods offer an alternative approach to uncertainty analysis that is attractive in part because of increasing usability of software. For more on Bayesian methods, see Gelman et al. (2003), Gilks et al. (1995), Robert and Casella (2004).

The U.S. EPA has made significant efforts to use probabilistic techniques to characterize uncertainty. These efforts have resulted in documents such as the March 1997 *Guiding Principles for Monte Carlo Analysis* (U.S. EPA, 1997a), the May 1997 Policy Statement (U.S. EPA, 1997b), and the December 2001 Superfund document *Risk Assessment Guidance for Superfund: Volume III—Part A, Process for Conducting Probabilistic Risk Assessment* (U.S. EPA, 2001).

2.7. LITERATURE REVIEW OF VARIABILITY AND UNCERTAINTY ANALYSIS

There has been a great deal of recent scholarly research in the area of uncertainty with the widespread use of computer simulation. Some of this research also incorporates issues related to variability. The purpose of the literature review below is to give a brief description of notable developments. Section 2.9 provides references for further research.

Cox (1999) argues that, based on information theory, models with greater complexity lead to more certain risk estimates. This may only be true if there is some degree of certainty in the assumptions used by the model. Uncertainties associated with the model need to be evaluated (NRC, 2009). These methods were discussed in Bogen and Spear (1987), Cox and Baybutt (1981), Rish and Marnicio (1988), and U.S. EPA (1985). Seiler (1987) discussed the analysis of error propagation with respect to general mathematical formulations typically found in risk assessment, such as linear combinations, powers of one variable, and multiplicative normally distributed variables. Even for large and uncertain errors, the formulations in Seiler (1987) are demonstrated to have practical value. Iman and Helton (1988) compared three methodologies for uncertainty and sensitivity analysis: (1) response surface analysis, (2) Latin hypercube sampling (with and without regression analysis), and (3) differential analysis. They found that Latin hypercube sampling with regression analysis had the best performance in terms of flexibility, estimate-ability, and ease of use. Saltelli (2002) and Frey (2002) offer views on the role of sensitivity analysis in risk assessment, and Frey and Patil (2002) compare methods for sensitivity analysis and recommend that two or more different sensitivity assessment methods should be used in order to obtain robust results. A Bayesian perspective on sensitivity analysis is described in Greenland (2001), who recommends that sensitivity analysis and Monte Carlo risk analysis should begin with specification of prior distributions, as in Bayesian analysis. Bayesian approaches to uncertainty analysis are described in Nayak and Kundu (2001).

Price et al. (1999) review the history of the inter-individual variability factor, as well as the relative merits of the sensitive population conceptual model versus the finite sample size model in determining the magnitude of the variability factor. They found that both models represent different sources of uncertainty and that both should be considered when developing inter-individual uncertainty factors. Uncertainties related to inter-individual and inter-species variability are treated in Hattis (1997) and Meek (2001), respectively. And Renwick (1999) demonstrates how inter-species and inter-individual uncertainty factors can be decomposed into kinetic and dynamic defaults by taking into account toxicodynamic and toxicokinetic differences. Burin and Saunders (1999) evaluate the robustness of the intra-species uncertainty factor and recommend intra-species uncertainty factoring in the range of 1-10.

Based on Monte Carlo analysis, Shlyakhter (1994) recommends inflation of estimated uncertainties by default safety factors in order to account for unsuspected uncertainties.

Jayjock (1997) defines uncertainty as either natural variability or lack of knowledge and also provides a demonstration of uncertainty and sensitivity analysis utilizing computer simulation. Additional approaches for coping with uncertainties in exposure modeling and monitoring are addressed by Nicas and Jayjock (2002).

Distributional risk assessment should be employed when data are available that support its use. Fayerweather et al. (1999) describe distributional risk assessment, as well as its strengths and weaknesses. Exposure metrics for distributional risk assessment using log-normal distributions of time spent showering (Burmaster, 1998a), water intake (Burmaster, 1998c), and body weight (Burmaster, 1998b; Burmaster and Crouch, 1997) have been developed. The lognormal distribution provides a succinct mathematical form that facilitates exposure and risk analyses. The fitted lognormal distribution is an approximation that should be carefully evaluated. One approach is to compare the lognormal distribution with other distributions (e.g., Weibull, Gamma). This is the approach used by Jacobs et al. (1998) and U.S. EPA (2002) in developing estimates of fish consumption and U.S. EPA (2004a) and Kahn and Stralka (2009) for estimates of water ingestion. These estimates were derived from the Continuing Survey of Food Intake by Individuals (CSFII), which was a Nationwide statistical survey of the population of the United States conducted by the U.S. Department of Agriculture. The CSFII collected extensive information on food and beverage intake from a sample that represented the population of the United States, and the sample weights provided with the data supported the estimation of empirical distributions of intakes for the entire population and various target populations such as intake distributions by various age categories. Kahn and Stralka (2008) used the CSFII data to estimate empirical distributions of water ingestion by pregnant and lactating women and compared the results to those presented by Burmaster (1998c). The comparison highlights the differences between the older data used by Burmaster and the CSFII and the differences between fitted approximate lognormal distributions and empirical distributions. The CSFII also collected data on body weight self-reported by respondents that supported the estimation of body-weight distributions by age categories, which are presented in Kahn and Stralka (2009). Detailed summary tables of results based on the CSFII data used by Kahn and Stralka (2009) are presented in Kahn (2008) personal communication (Kahn, 2008).

When sensitivity analysis or uncertainty propagation analysis indicates that a parameter profoundly influences exposure estimates, the assessor should, if possible, develop a probabilistic description of its range. It is also possible to use estimates derived from a large-scale survey such as the CSFII as a basis for alternative parameter values that may be used in a sensitivity analysis. The CSFII provides the basis for an objective point of reference for food and beverage intake variables, which are critical components of many risk and exposure assessments. For example, an assumed value for a mean or upper percentile could be compared to a suitable value from the CSFII to assess sensitivity. Deterministic and probabilistic approaches to risk assessment are reviewed for non-carcinogenic health effects in Kalbelah et al. (2003), with attention to quantifying sources of uncertainty. Kelly and Campbell (2000) review guidance for conducting Monte Carlo analysis and clarify the distinction between variability and uncertainty. This distinction is represented by two-stage Monte Carlo simulation, where a probability distribution represents variability in a population, while a separate distribution for uncertainty defines the degree of variation in the parameters of the population variability distribution. Another example of two-stage Monte Carlo simulation is given in Xue et al. (2006). Price et al. (1997) utilize a Monte Carlo approach to characterize uncertainties for a method aimed at estimating the probability of adverse, non-cancer health effects for exposures exceeding the reference dose. Their method relies on general toxicologic information for a compound, such as the no-observed-adverse-effect-level dose (NOAEL). Semple et al. (2003) examine uncertainty arising in reconstructed exposure estimates using Monte Carlo methods. Uncertainty in PBPK models is discussed in Simon (1997) and Bois (2010). Slob and Pieters (1998) propose replacing uncertainty factors with probabilistic uncertainty distributions and discuss how uncertainties may be quantified for animal NOAELs and extrapolation factors. Zheng and Frey (2005) demonstrate the use of Monte Carlo methods for characterizing uncertainty and emphasize that uncertainty estimates will be biased if contributions from sampling error and measurement error are not accounted for separately.

Distributional biometric data for probabilistic risk assessment are available for some exposure factors. Empirical distributions are provided in this handbook when available. If the data are unavailable or otherwise inadequate, expert judgment can be used to generate a subjective probabilistic representation. Such judgments should be developed in a consistent, well-documented manner. Morgan et al. (1990) and Rish (1988) describe techniques to solicit expert judgment, while Weiss (2001) demonstrates use of a Web-based survey.

Standard statistical methods may be less cumbersome than a probabilistic approach and may be preferred, if there are enough data to justify their use and they are sufficient to support the environmental decision needed. Epidemiologic analyses may, for example, be used to estimate variability in human populations, as in Peretz et al. (1997), who describe variation in exposure time. Sources of variation and uncertainty may also be explored and quantified using a linear regression modeling framework, as in Robinson and Hurst (1997). A general framework for statistical assessment of uncertainty and variance is given for additive and multiplicative models in Rai et al. (1996) and Rai and Krewski (1998), respectively. Wallace and Williams (2005) describe a robust method for estimating long-term exposures based on short-term measurements.

In addition to the use of defaults and quantitative analysis, exposure and risk assessors often rely on expert judgment when information is insufficient to establish uncertainty bounds (NRC, 2009). There are, however, some biases introduced during expert elicitation. Some of these include availability, anchoring and adjustment, representativeness, disqualification, belief in "law of small numbers," and overconfidence (NRC, 2009). Availability refers to the tendency to assign greater probability to commonly encountered or frequently mentioned events (NRC, 2009). Anchoring and adjustment is the tendency to be over-influenced by the first information seen or provided (NRC, 2009). Representativeness is the tendency to judge an event by reference to another (NRC, 2009). Disqualification is the tendency to ignore data or evidence that contradicts strongly held convictions (NRC, 2009). The belief in the "law of small numbers" is to believe that small samples from a population are more representative than is justified (NRC, 2009). Overconfidence is the tendency of experts to belief that their answers are correct (NRC, 2009).

2.8. PRESENTING RESULTS OF VARIABILITY AND UNCERTAINTY ANALYSES

The risk assessor is advised to distinguish between variability of exposure and associated uncertainties. A risk assessment should include three components involving elements of variability and uncertainty: (1) the estimated risk itself (X), (2) the level of confidence (Y) that the risk is no higher than X, and (3) the percent of the population (Z) that X is intended to apply to in a variable population (NRC, 1994). This information will provide risk managers with a better understanding of how exposures are distributed over the population and of the certainty of the exposure assessment.

Sometimes analyzing all exposure scenarios is unfeasible. At minimum, the assessor should describe the rationale for excluding reasonable exposure scenarios; characterize the uncertainty in these decisions as high, medium, or low; and state whether they were based on data, analogy, or professional judgment. Where uncertainty is high, a sensitivity analysis can be used to estimate upper limits on exposure by way of a series of "what if" questions.

Although assessors have historically used descriptors (e.g., high-end, worst case, average) to communicate risk variability, the 1992 *Guidelines for Exposure Assessment* (U.S. EPA, 1992) established quantitative definitions for these risk descriptors. The data presented in this handbook are one of the tools available to exposure assessors to construct the various risk descriptors. A thorough risk assessment should include particular assumptions about human behavior and biology that are a result of variability. A useful example is given in NRC (1994):

> "…a poor risk characterization for a hazardous air pollutant might say 'The risk number R is a plausible upper bound.'" A better characterization would say, "The risk number R applies to a person of reasonably high-end behavior living at the fenceline 8 hours a day for 35 years."

In addition to presenting variability in exposure, frequently, exposure assessments include an uncertainty analysis. An exposure assessment will include assumptions about the contaminant, contaminant exposure routes and pathways, location, time, population characteristics, and susceptibilities. Each of these assumptions may be associated with uncertainties. Uncertainties may be presented using a variety of techniques, depending on the requirements of the assessment, the amount of data available, and the audience. Simple techniques include risk designations, i.e., high, medium, or low (un)certainties. Sophisticated techniques may include quantitative descriptions of the uncertainty analysis or graphical representations.

The exposure assessor may need to make many decisions regarding the use of existing information in constructing scenarios and setting up the exposure equations. In presenting the scenario results, the assessor should strive for a balanced and impartial treatment of the evidence bearing on the conclusions with the key assumptions highlighted. For these key assumptions, one should cite data sources and explain any adjustments of the data.

The exposure assessor should describe the rationale for any conceptual or mathematical models. This discussion should address their verification and validation status, how well they represent the situation being assessed (e.g., average versus high-end estimates), and any plausible alternatives in terms of their acceptance by the scientific community.

To the extent possible, this handbook provides information that can be used in a risk assessment to characterize variability, and to some extent, uncertainty. In general, variability is addressed by providing probability distributions, where available, or qualitative discussions of the data sets used. Uncertainty is addressed by applying confidence ratings to the recommendations provided for the various factors, along with detailed discussions of any limitations of the data presented.

2.9. REFERENCES FOR CHAPTER 2

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3. INGESTION OF WATER AND OTHER SELECT LIQUIDS

3.1. INTRODUCTION

Water ingestion is another pathway of exposure to environmental chemicals. Contamination of water may occur at the water supply source (ground water or surface water); during treatment (for example, toxic by-products may be formed during chlorination); or post-treatment (such as leaching of lead or other materials from plumbing systems). People may be exposed to contaminants in water when consuming water directly as a beverage, indirectly from foods and drinks made with water, or incidentally while swimming. Estimating the magnitude of the potential dose of toxics from water ingestion requires information on the quantity of water consumed. The purpose of this section is to describe key and relevant published studies that provide information on water ingestion for various populations and to provide recommended ingestion rate values for use in exposure assessments. The studies described in this section provide information on ingestion of water consumed as a beverage, ingestion of other select liquids, and ingestion of water while swimming. Historically, the U.S. Environmental Protection Agency (EPA) has assumed a drinking water ingestion rate of 2 L/day for adults and 1 L/day for infants and children under 10 years of age (U.S. EPA, 2000). This rate includes water consumed in the form of juices and other beverages containing tap water. The National Research Council (NRC, 1977) estimated that daily consumption of water may vary with levels of physical activity and fluctuations in temperature and humidity. It is reasonable to assume that people engaging in physically-demanding activities or living in warmer regions may have higher levels of water ingestion. However, there is limited information on the effects of activity level and climatic conditions on water ingestion.

The U.S. EPA selected the analysis by Kahn and Stralka (2009) and Kahn (2008) of the (USDA's) 1994–1996, 1998 Continuing Survey of Food Intake by Individuals (CSFII) as a key study of drinking water ingestion for the general population of children <3 years of age. U.S. EPA's 2010 analysis of 2003-2006 data from the National Health and Nutrition Examination Survey (NHANES) was selected as a key study of drinking water ingestion for the general population of individuals ≥3 years of age. Although NHANES 2003–2006 contains the most up-to-date information on water intake rates, estimates for children <3 years of age obtained from the NHANES survey are less reliable due to sample size limitations. Kahn and Stralka (2008) was selected as a key study of drinking water ingestion for pregnant and lactating women. Kahn and Stralka (2008) used data from U.S. Department of Agriculture's (USDA's) 1994–1996, 1998 Continuing Survey of Food Intake by Individuals (CSFII). The 2010 U.S. EPA analysis of NHANES data and the analyses by Kahn (2008) and Kahn and Stralka (2009; 2008) generated ingestion rates for direct and indirect ingestion of water. *Direct ingestion* is defined as direct consumption of water as a beverage, while *indirect ingestion* includes water added during food preparation but not water intrinsic to purchased foods (i.e., water that is naturally contained in foods) (Kahn and Stralka, 2009; Kahn and Stralka, 2008). Data for consumption of water from various sources (i.e., the community water supply, bottled water, and other sources) are also presented. It is noted that the type of water people are drinking has changed in the last decade, as evidenced by the increase in bottled water consumption. However, the majority of the U.S. population consumes water from public (i.e., community) water distribution systems; about 15% of the U.S. population obtains their water from private (i.e., household) wells, cisterns, or springs (U.S. EPA, 2002). Regardless of the source of the water, the physiological need for water should be the same among populations using community or private water systems. For the purposes of exposure assessments involving site-specific contaminated drinking water, ingestion rates based on the community supply are most appropriate. Given the assumption that bottled water, and purchased foods and beverages that contain water are widely distributed and less likely to contain source-specific water, the use of total water ingestion rates may overestimate the potential exposure to toxic substances present only in local water supplies; therefore, tap water ingestion of community water, rather than total water ingestion, is emphasized in this section.

The key studies on water ingestion for the general population (CSFII and NHANES) and the population of pregnant/lactating women (CSFII) are both based on short-term survey data (2 days). Although short-term data may be suitable for obtaining mean or median ingestion values that are representative of both short- and long-term ingestion distributions, upper- and lower-percentile values may be different for short-term and long-term data. It should also be noted that most currently available water ingestion surveys are based on respondent recall. This may be a source of uncertainty in the estimated ingestion rates because of the subjective nature of this type of survey technique. Percentile distributions for water ingestion are presented in this handbook, where sufficient data are available. Data are not provided for the location of water consumption (i.e., home, school, daycare center, etc.).

Limited information was available regarding incidental ingestion of water while swimming. A recent pilot study (Dufour et al., 2006) has provided some quantitative experimental data on water ingestion among swimmers. These data are provided in this chapter.

Section 3.2 provides the recommendations and confidence ratings for water ingestion among the general population and pregnant and lactating women, and among swimmers. Section 3.2.1 provides the key studies for general water ingestion rates, Section 3.4.1 provides ingestion rates for pregnant and lactating women, and Section 3.6.1 provides ingestion rates for swimming. For water ingestion at high activity levels or hot climates, no recommendations are provided, but Section 3.5 includes relevant studies. Relevant studies on all subcategories of water ingestion are also presented to provide the reader with added perspective on the current state-of-knowledge pertaining to ingestion of water and select liquids.

3.2. RECOMMENDATIONS

3.2.1. Water Ingestion From Consumption of Water as a Beverage and From Food and Drink

The recommended water ingestion from the consumption of water as a beverage and from foods and drinks are based on Kahn and Stralka (2009) and Kahn (2008) for children <3 years of age and on U.S. EPA's 2010 analysis of NHANES data from 2003–2006 for individuals ≥3 years of age. Table 3-1 presents a summary of the recommended values for direct and indirect ingestion of community water. Per capita mean and 95th percentile values range from 184 mL/day to 1,046 mL/day and 837 mL/day to 2,958 mL/day, respectively, depending on the age group. Consumer-only mean and 95th percentile values range from 308 mL/day to 1,288 mL/day and 858 mL/day to 3,092 mL/day, respectively, depending on the age group. Per capita intake rates represent intake that has been averaged over the entire population (including those individuals that reported no intake). In general, per capita intake rates are appropriate for use in exposure assessments for which average daily dose estimates are of interest because they represent both individuals who drank water during the survey period and individuals who may drink water at some time but did not consume it during the survey period. Consumer-only intake rates represent the quantity of water consumed only by individuals who reported water intake during the survey period. Table 3-2 presents a characterization of the overall confidence in the accuracy and appropriateness of the recommendations for drinking water intake.

3.2.2. Pregnant and Lactating Women

Based upon the results of Kahn and Stralka (2008), per capita mean and 95th percentile values for ingestion of drinking water among pregnant women were 819 mL/day and 2,503 mL/day, respectively. The per capita mean and 95th percentile values for lactating women were 1,379 mL/day and 3,434 mL/day, respectively. Table 3-3 presents a summary of the recommended values for water ingestion rates. Table 3-4 presents the confidence ratings for these recommendations.

3.2.3. Water Ingestion While Swimming or Diving

Based on the results of the Dufour et al. (2006) study, mean water ingestion rates of 49 mL/hour for children under 18 years of age and 21 mL/hour for adults are recommended for exposure scenarios involving swimming activities. Although these estimates were derived from swimming pool experiments, Dufour et al. (2006) noted that swimming behavior of recreational pool swimmers may be similar to freshwater swimmers. Estimates may be different for salt water swimmers and competitive swimmers. The recommended upper percentile water ingestion rate for swimming activities among children is based on the 97th percentile value of 120 mL/hour (90 mL/0.75 hour) from Dufour et al. (2006). Because the data set for adults is limited, the maximum value observed in the Dufour et al. (2006) study is used as an upper percentile value for adults: 71 mL/hour (53 mL/0.75 hour). Table 3-5 presents a summary of the recommended values for water ingestion rates. Table 3-6 presents the confidence ratings for these recommendations. Data on the amount of time spent swimming can be found in Chapter 16 (see Table 16-1) of this handbook.

Table 3-1. Recommended Values for Drinking Water Ingestion Rates[a]

Age Group	Mean		95th Percentile		Multiple Percentiles
	mL/day	mL/kg-day	mL/day	mL/kg-day	
Per Capita[b]					
Birth to <1 month[c]	184	52	839[d]	232[d]	See Table 3-7 and Table 3-11 for children <3 years old and Table 3-23 and Table 3-28 for individuals >3 years old.
1 to <3 months[c]	227	48	896[d]	205[d]	
3 to <6 months[c]	362	52	1,056	159	
6 to <12 months[c]	360	41	1,055	126	
1 to <2 years[c]	271	23	837	71	
2 to <3 years[c]	317	23	877	60	
3 to <6 years	327	18	959	51	
6 to <11 years	414	14	1,316	43	
11 to <16 years	520	10	1,821	32	
16 to <18 years	573	9	1,783	28	
18 to <21 years	681	9	2,368	35	
≥21 years	1,043	13	2,958	40	
>65 years	1,046	14	2,730	40	
All ages[e]	869	14	2,717	42	
Consumers Only[f]					
Birth to <1 month[c]	470[d]	137[d]	858[d]	238[d]	See Table 3-15 and Table 3-19 for children <3 years old and Table 3-33 and Table 3-38 for individuals >3 years old.
1 to <3 months[c]	552	119	1,053[d]	285[d]	
3 to <6 months[c]	556	80	1,171[d]	173[d]	
6 to <12 months[c]	467	53	1,147	129	
1 to <2 years[c]	308	27	893	75	
2 to <3 years[c]	356	26	912	62	
3 to <6 years	382	21	999	52	
6 to <11 years	511	17	1,404	47	
11 to <16 years	637	12	1,976	35	
16 to <18 years	702	10	1,883	30	
18 to <21 years	816	11	2,818	36	
≥21 years	1,227	16	3,092	42	
>65 years	1,288	18	2,960	43	
All ages[e]	1,033	16	2,881	44	

[a] Ingestion rates for combined direct and indirect water from community water supply.
[b] Per capita intake rates are generated by averaging consumer-only intakes over the entire population (including those individuals that reported no intake).
[c] Based on Kahn and Stralka (2009) and Kahn (2008).
[d] Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993).
[e] Based on U.S. EPA analysis of NHANES 2003–2006 data.
[f] Consumer-only intake represents the quantity of water consumed only by individuals that reported consuming water during the survey period.

Source: Kahn and Stralka (2009); Kahn (2008); U.S. EPA analysis of NHANES 2003–2006 data.

Table 3-2. Confidence in Recommendations for Drinking Water Ingestion Rates		
General Assessment Factors	**Rationale**	**Rating**
Soundness		Medium to High
Adequacy of Approach	The survey methodology and data analysis were adequate. The surveys sampled approximately 20,000 individuals (CSFII) and 18,000 (NHANES) individuals; sample size varied with age.	
Minimal (or defined) Bias	No physical measurements were taken. The method relied on recent recall of standardized volumes of drinking water containers.	
Applicability and Utility		High
Exposure Factor of Interest	The key studies were directly relevant to water ingestion.	
Representativeness	The data were demographically representative (based on stratified random sample). Sample sizes for some age groups were limited.	
Currency	Data were collected between 1994 and 1998 for CSFII and between 2003 and 2006 for NHANES.	
Data Collection Period	Data were collected for 2 non-consecutive days. However, long-term variability may be small. Use of a short-term average as a chronic ingestion measure can be assumed.	
Clarity and Completeness		High
Accessibility	The CSFII and NHANES data are publicly available.	
Reproducibility	The methodology was clearly presented; enough information was included to reproduce the results.	
Quality Assurance	CSFII and NHANES data collection follow strict QA/QC procedures. Quality control of the secondary data analysis was not well described.	
Variability and Uncertainty		High
Variability in Population	Full distributions were developed.	
Uncertainty	Except for data collection based on recall, sources of uncertainty were minimal.	
Evaluation and Review		Medium
Peer Review	The CSFII and NHANES surveys received a high level of peer review. The CSFII data were published in the peer-reviewed literature. The U.S. EPA analysis of NHANES has not been peer-reviewed outside the Agency.	
Number and Agreement of Studies	There were two key studies for drinking water ingestion among the general population.	
Overall Rating		**Medium to High**, **Low** for footnote "d" on Table 3-1

Table 3-3. Recommended Values for Water Ingestion Rates of Community Water for Pregnant and Lactating Women[a]

Group	Mean		95th Percentile	
Per Capita[b]				
	mL/day	mL/kg-day	mL/day	mL/kg-day
Pregnant women	819[c]	13[c]	2,503[c]	43[c]
Lactating women	1,379[c]	21[c]	3,434[c]	55[c]
Consumers Only[d]				
	mL/day	mL/kg-day	mL/day	mL/kg-day
Pregnant women	872[c]	14[c]	2,589[c]	43[c]
Lactating women	1,665[c]	26[c]	3,588[c]	55[c]

[a] Ingestion rates for combined direct and indirect water from community water supply.

[b] Per capita intake rates are generated by averaging consumer-only intakes over the entire population (including those individuals that reported no intake).

[c] Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993).

[d] Consumer-only intake represents the quantity of water consumed only by individuals that reported consuming water during the survey period.

Source: Kahn and Stralka (2008).

Table 3-4. Confidence in Recommendations for Water Ingestion for Pregnant/Lactating Women

General Assessment Factors	Rationale	Rating
Soundness		Low
Adequacy of Approach	The survey methodology and data analysis were adequate. The sample size was small, approximately 99 pregnant and lactating women.	
Minimal (or defined) Bias	No physical measurements were taken. The method relied on recent recall of standardized volumes of drinking water containers.	
Applicability and Utility		Low to Medium
Exposure Factor of Interest	The key study was directly relevant to water ingestion.	
Representativeness	The data were demographically representative (based on stratified random sample).	
Currency	Data were collected between 1994 and 1998.	
Data Collection Period	Data were collected for 2 non-consecutive days. However, long-term variability may be small. Use of a short-term average as a chronic ingestion measure can be assumed.	
Clarity and Completeness		Medium
Accessibility	The CSFII data are publicly available. The Kahn and Stralka (2008) analysis of the CSFII 1994–1996, 1998 data was published in a peer-reviewed journal.	
Reproducibility	The methodology was clearly presented; enough information was included to reproduce the results.	
Quality Assurance	Quality assurance of the CSFII data was good; quality control of the secondary data analysis was not well described.	
Variability and Uncertainty		Low
Variability in Population	Full distributions were given in a separate document (Kahn, 2008).	
Uncertainty	Except for data collection based on recall, sources of uncertainty were minimal.	
Evaluation and Review		Medium
Peer Review	The USDA CSFII survey received a high level of peer review. The Kahn and Stralka (2008) study was published in a peer-reviewed journal.	
Number and Agreement of Studies	There was one key study for pregnant/lactating women water ingestion.	
Overall Rating		**Low**

Table 3-5. Recommended Values for Water Ingestion While Swimming

Age Group	Mean		Upper Percentile	
	mL/event[a]	mL/hour	mL/event[a]	mL/hour
Children	37	49	90[b]	120[b]
Adults	16	21	53[c]	71[c]

[a] Participants swam for 45 minutes.
[b] 97th percentile.
[c] Based on maximum value.

Source: Dufour et al. (2006).

Table 3-6. Confidence in Recommendations for Water Ingestion While Swimming		
General Assessment Factors	**Rationale**	**Rating**
Soundness		Medium
Adequacy of Approach	The approach appears to be appropriate given that cyanuric acid (a tracer used in treated pool water) is not metabolized, but the sample size was small (41 children and 12 adults). The Dufour et al. (2006) study analyzed primary data on water ingestion during swimming.	
Minimal (or defined) Bias	Data were collected over a period of 45 minutes; this may not accurately reflect the time spent by a recreational swimmer.	
Applicability and Utility		Low to Medium
Exposure Factor of Interest	The key study was directly relevant to water ingestion while swimming.	
Representativeness	The sample was not representative of the U.S. population. Data cannot be divided into by age categories.	
Currency	It appears that the study was conducted in 2005.	
Data Collection Period	Data were collected over a period of 45 minutes.	
Clarity and Completeness		Medium
Accessibility	The Dufour et al. (2006) study was published in a peer-reviewed journal.	
Reproducibility	The methodology was clearly presented; enough information was included to reproduce the results.	
Quality Assurance	Quality assurance methods were not described in the study.	
Variability and Uncertainty		Low
Variability in Population	Full distributions were not available. Data were not broken out by age groups.	
Uncertainty	There were multiple sources of uncertainty (e.g., sample population may not reflect swimming practices for all swimmers, rates based on swimming duration of 45 minutes, differences by age group not defined).	
Evaluation and Review		Medium
Peer Review	Dufour et al. (2006) was published in a peer-reviewed journal.	
Number and Agreement of Studies	There was one key study for ingestion of water when swimming.	
Overall Rating		**Low**

3.3. DRINKING WATER INGESTION STUDIES

3.3.1. Key Drinking Water Ingestion Study

3.3.1.1. *Kahn and Stralka (2009)—Estimated Daily Average Per Capita Water Ingestion by Child and Adult Age Categories Based on USDA's 1994–1996 and 1998 Continuing Survey of Food Intakes by Individuals and Supplemental Data, Kahn (2008)*

Kahn and Stralka (2009) analyzed the combined 1994–1996 and 1998 CSFII data sets to examine water ingestion rates of more than 20,000 individuals surveyed, including approximately 10,000 under age 21 and 9,000 under age 11. USDA surveyed households in the United States and District of Columbia and collected food and beverage recall data as part of the CSFII (USDA, 2000). Data were collected by an in-home interviewer. The Day 2 interview was conducted 3 to 10 days later and on a different day of the week. Each individual in the survey was assigned a sample weight based on his or her demographic data. These weights were taken into account when calculating mean and percentile water ingestion rates from various sources. Kahn and Stralka (2009) derived mean and percentile estimates of daily average water ingestion for the following age categories: <1 month, 1 to <3 months, 3 to <6 months, 6 to <12 months, 1 to <2 years of age, 2 to <3 years, 3 to <6 years, 6 to <11 years, 11 to <16 years, 16 to <18 years, 18 to <21 years of age, 21 years and older, 65 years and older, and all ages. The increased sample size for children younger than 11 years of age (from 4,339 in the initial 1994–1996 survey to 9,643 children in the combined 1994–1996, 1998 survey) enabled water ingestion estimates to be categorized into the finer age categories recommended by U.S. EPA (2005). Consumer-only and per capita water ingestion estimates were reported in the Kahn and Stralka (2009) study for two water source categories: all sources and community water. "All sources" included water from all supply sources such as community water supply (i.e., tap water), bottled water, other sources, and missing sources. "Community water" included tap water from a community or municipal water supply. Other sources included wells, springs, and cisterns; missing sources represented water sources that the survey respondent was unable to identify. The water ingestion estimates included both water ingested directly as a beverage (direct water) and water added to foods and beverages during final preparation at home or by local food service establishments such as school cafeterias and restaurants (indirect water). Commercial water added by a manufacturer (i.e., water contained in soda or beer) and intrinsic water in foods and liquids (i.e., milk and natural undiluted juice) were not included in the estimates. Kahn and Stralka (2009) only reported the mean and 90th and 95th percentile estimates of per capita and consumer-only ingestion. The full distributions of ingestion estimates were provided by the author (Kahn, 2008). Table 3-7 to Table 3-22 presents full distributions for the various water source categories (community water, bottled water, other sources, and all sources). Table 3-7 to Table 3-10 provide per capita ingestion estimates of total water (combined direct and indirect water) in mL/day for the various water source categories (i.e., community, bottled, other, and all sources). Table 3-11 to Table 3-14 present the same information as Table 3-7 to Table 3-10 but in units of mL/kg-day. Table 3-15 to Table 3-18 provide consumer-only combined direct and indirect water ingestion estimates in mL/day for the various source categories. Table 3-19 to Table 3-22 present the same information as Table 3-15 to Table 3-18 but in units of mL/kg-day. Estimates that do not meet the minimum sample size requirements as described in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993) are flagged in the tables.

The CSFII 1994–1996, 1998 data have both strengths and limitations with regard to estimating water ingestion. These are discussed in detail in U.S. EPA (2004) and Kahn and Stralka (2009). The principal advantages of this survey are that (1) it was designed to be representative of the United States population, including children and low income groups, (2) sample weights were provided that facilitated proper analysis of the data and accounted for non-response; and (3) the number of individuals sampled (more than 20,000) is sufficient to allow categorization within narrowly defined age categories. One limitation of this survey is that data were collected for only 2 days. As discussed in Section 3.3.1.2 with regard to U.S. EPA's analysis of NHANES data, short-term data may not accurately reflect long-term intake patterns, especially at the extremes (i.e., tails) of the distribution of water intake. This study is considered key because the sample size for children less than 3 years of age are larger than in the most up-to-date information from NHANES 2003–2006 (see Section 3.3.1.2). Therefore, recommendations for these age groups are based on this analysis.

3.3.1.2. *U.S. EPA Analysis of NHANES 2003–2006 Data*

In 2010, U.S. EPA analyzed the combined 2003-2004 and 2005–2006 NHANES data sets to examine water ingestion rates for the general population. The 2003–2006 data set included information on more than 18,000 individuals surveyed, including approximately 10,000 under age 21 and 5,000 under age 11. The U.S. Centers for Disease Control and Prevention surveyed households across the United States and collected food and beverage recall data as part of the NHANES. The first dietary recall interview was conducted in-person in a Mobile Examination Center, and the second was collected by telephone 3 to 10 days later on a different day of the week. Each individual in the survey was assigned a sample weight based on his or her demographic data. These weights were taken into account when calculating mean and percentile water ingestion rates from various sources.

In 2010, U.S. EPA, Office of Pesticide Programs used NHANES 2003–2006 data to update the Food Commodity Intake Database (FCID) that was developed in earlier analyses of data from the USDA's CSFII (U.S. EPA, 2000; USDA, 2000). In FCID, NHANES data on the foods people reported eating were converted to the quantities of agricultural commodities eaten, including water that was added in the preparation of foods and beverages. FCID was used in the U.S. EPA analysis to derive estimates of water that was ingested from the consumption of foods and beverages.

U.S. EPA derived mean and percentile estimates of daily average water ingestion for the following age categories: Birth to <1 month, 1 to <3 months, 3 to <6 months, 6 to <12 months, 1 to <2 years of age, 2 to <3 years, 3 to <6 years, 6 to <11 years, 11 to <16 years, 16 to <18 years, and 18 to <21 years of age, 21 years and older, 65 years and older, and all ages.

Consumer-only and per capita water ingestion estimates were generated for four water source categories: community water, bottled water, other sources, and all sources. Consumer-only intake represents the quantity of water consumed by individuals during the survey period. These data are generated by averaging intake across only the individuals in the survey who reported consumption of water. Per capita intake rates are generated by averaging consumer-only intakes over the entire population (including those individuals that reported no intake). In general, per capita intake rates are appropriate for use in exposure assessments for which average dose estimates are of interest because they represent both individuals who drank water during the survey period and individuals who may drink water at some time but did not consume it during the survey period. "All sources" included water from all supply sources such as community water supply (i.e., tap water), bottled water, other sources, and missing/unknown sources. "Community water" included tap water from a community or municipal water supply. "Other sources" included wells, springs, cisterns, other non-specified sources, and missing/unknown sources that the survey respondent was unable to identify. The water ingestion estimates included both water ingested directly as a beverage (direct water) and water added to foods and beverages during final preparation at home or by local food service establishments such as school cafeterias and restaurants (indirect water). Commercial water added by a manufacturer (i.e., water contained in soda or beer) and intrinsic water in foods and liquids (i.e., milk and natural undiluted juice) were not included in the estimates. NHANES water consumption respondent data were averaged over both days of dietary data when they were available; otherwise, 1-day data were used. Intake rate distributions were provided in units of mL/day and mL/kg-day. The body weights of survey participants were used in developing intake rate estimates in units of mL/kg-day.

Table 3-23 to Table 3-42 present full distributions for the various water source categories (community water, bottled water, other sources, and all sources). Table 3-23 to Table 3-26 provide per capita ingestion estimates of total water (combined direct and indirect water) in mL/day for the various water source categories (i.e., community, bottled, other, and all sources). Table 3-27 presents the 90% confidence intervals (CIs) around the estimated means and the 90% bootstrap intervals (BIs) around the 90th and 95th percentiles of total water ingestion from all water sources. Table 3-28 to Table 3-32 present the same information as Table 3-23 to Table 3-27 but in units of mL/kg-day. Table 3-33 to Table 3-36 provide consumer-only combined direct and indirect water ingestion estimates in mL/day for the various source categories. Table 3-37 presents confidence and bootstrap intervals for total water ingestion estimates by consumers only from all sources. Table 3-38 to Table 3-42 present the same information as Table 3-33 to Table 3-37 but in units of mL/kg-day. Estimates that do not meet the minimum sample size as described in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group*

Recommendations (NCHS, 1993), are flagged in the tables. The design effect used to determine the minimum required sample size was domain specific (i.e., calculated separately for various age groups). The data show that the total quantity of water ingested from all sources per unit mass of body weight was at a maximum in the first half year of life and decreased with increasing age. When indexed to body weight, the per capita ingestion rate of water from all sources combined for children under 6 months of age was approximately 2.5 times higher than that of adults ≥21 years (see Table 3-31), and consumers younger than 6 months of age ingested approximately 3.5 times the amount of water (all sources combined) as adults (see Table 3-41). The pattern of decreasing water ingestion per unit of body weight was also observed in consumer-only estimates of community water (see Table 3-38), and other sources (see Table 3-40). However, this trend was not observed in per capita estimates of community water, bottled water, and other sources due to the lack of available responses under these age and water source categories.

It should be noted that per capita estimates of water intake from all sources using the NHANES 2003–2006 data are higher than estimates derived previously from CSFII 1994–1996, 1998 for adults (see Section 3.3.1.1). Among adults, total per-capita water consumption increased by 234 mL, or 16%. Per-capita bottled water consumption among adults nearly doubled, from 189 to 375 mL/day. Among infants, there appear to be erratic changes in water consumption patterns. In particular, ingestion rate estimates of bottled water for children <12 months old are considerably less when compared to values obtained from CSFII. This is due to the fact that NHANES does not allow for the allocation of any bottled water consumed indirectly in the preparation of foods and beverages. This may have an impact on the bottled water consumption for infants whose formula is prepared with bottled water. Among older children and adolescents, overall water consumption increased by 0% to 10%, and bottled water consumption increased 25% to 211%. Almost none of the NHANES—CSFII differences are statistically significant, except for all adults and all respondents, which have very large sample sizes.

The advantages of U.S. EPA's analysis of the 2003–2006 NHANES surveys are (1) that the surveys were designed to obtain statistically valid sample of the civilian non-institutionalized U.S. population (i.e., the sampling frame was organized using 2000 U.S. population census estimates); (2) NHANES oversampled low income persons, adolescents 12-19 years, persons 60 years and older, Blacks, and Mexican Americans; (3) several sets of sampling weights were available for use with the intake data to facilitate proper analysis of the data; (4) the sample size was sufficient to allow categorization within narrowly defined age categories, and the large sample provided useful information on the overall distribution of ingestion by the population and should adequately reflect the range among respondent variability; (5) the survey was conducted over 2 non-consecutive days, which improved the variance over consecutive days of consumption; and (6) the most current data set was used. One limitation of the data is that the data were collected over only 2 days and do not necessarily represent "usual" intake. "Usual dietary intake" refers to the long-term average of daily intakes by an individual. Thus, water ingestion estimates based on short-term data may differ from long-term rates, especially at the tails of the distribution. There are, however, several limitations associated with these data. Water intake estimates for children under 3 years of age are less statistically reliable due to sample size. In addition, NHANES does not allow for the allocation of indirect water intake in the estimation of bottled water consumption. Another limitation of these data is that the survey design, while being well-tailored for the overall population of the United States and conducted throughout the year to account for seasonal variation, is of limited utility for assessing small and potentially at-risk populations based on ethnicity, medical status, geography/climate, or other factors such as activity level.

3.3.2. Relevant Drinking Water Ingestion Studies

3.3.2.1. *Wolf (1958)—Body Water Content*

Wolf (1958) provided information on the water content of human bodies. Wolf (1958) stated that a newborn baby is about 77% water while an adult male is about 60% water by weight. An adult male gains and loses about 2,750 mL of water each day. Water intake in dissimilar mammals varies according to 0.88 power of body weight.

3.3.2.2. *National Research Council (1977)—Drinking Water and Health*

NRC (1977) calculated the average per capita water (liquid) consumption per day to be 1.63 L. This figure was based on a survey of the following literature sources: Starling (1941); Bourne and Kidder (1953); Walker et al. (1957); Wolf (1958); Guyton (1968); McNall and Schlegel (1968); Randall (1973); NRC (1974); and Pike and Brown (1975), as cited in NRC (1977). Although the calculated average intake rate was 1.63 L/day, NRC (1977) adopted a larger rate (2 L/day) to represent the intake of the majority of water consumers. This value is relatively consistent with the total tap water intakes rate estimated from the key study presented previously. However, the use of the term "liquid" was not clearly defined in this study, and it is not known whether the populations surveyed are representative of the adult U.S. population. Consequently, the results of this study are of limited use in recommending total tap water intake rates, and this study is not considered a key study.

3.3.2.3. *Hopkins and Ellis (1980)—Drinking Water Consumption in Great Britain*

A study conducted in Great Britain over a 6-week period during September and October 1978, estimated the drinking water consumption rates of 3,564 individuals from 1,320 households in England, Scotland, and Wales (Hopkins and Ellis, 1980). The participants were selected randomly and were asked to complete a questionnaire and a diary indicating the type and quantity of beverages consumed over a 1-week period. Total liquid intake included total tap water taken at home and away from home; purchased alcoholic beverages; and non-tap water-based drinks. Total tap water included water content of tea, coffee, and other hot water drinks; homemade alcoholic beverages; and tap water consumed directly as a beverage. Table 3-43 presents the assumed tap water contents for these beverages. Based on responses from 3,564 participants, the mean intake rates and frequency distribution data for various beverage categories were estimated by Hopkins and Ellis (1980). Table 3-44 lists these data. The mean per capita total liquid intake rate for all individuals surveyed was 1.59 L/day, and the mean per capita total tap water intake rate was 0.96 L/day, with a 90th percentile value of about 1.57 L/day. Liquid intake rates were also estimated for males and females in various age groups. Table 3-45 summarizes the total liquid and total tap water intake rates for 1,758 males and 1,800 females grouped into six age categories (Hopkins and Ellis, 1980). The mean and 90th percentile total tap water intake values for adults over age 18 years are, respectively, 1.07 L/day and 1.87 L/day, as determined by pooling data for males and females for the three adult age ranges in Table 3-45. This calculation assumes, as does Table 3-44 and Table 3-45, that the underlying distribution is normal and not lognormal.

The advantage of these data is that the responses were not generated on a recall basis but by recording daily intake in diaries. The latter approach may result in more accurate responses being generated. Diaries were maintained for 1 week, which is longer than other surveys (e.g., CSFII). The use of total liquid and total tap water was well defined in this study. Also, these data were based on the population of Great Britain and not the United States. Drinking patterns may differ among these populations as a result of varying weather conditions and socioeconomic factors. For these reasons, this study is not considered a key study in this document.

3.3.2.4. *Canadian Ministry of National Health and Welfare (1981)—Tap Water Consumption in Canada*

In a study conducted by the Canadian Ministry of National Health and Welfare, 970 individuals from 295 households were surveyed to determine the per capita total tap water intake rates for various age/sex groups during winter and summer seasons (Canadian Ministry of National Health and Welfare, 1981). Intake rate was also evaluated as a function of physical activity. The population that was surveyed matched the Canadian 1976 census with respect to the proportion in different age, regional, community size, and dwelling type groups. Participants monitored water intake for a 2-day period (1 weekday, and 1 weekend day) in both late summer of 1977 and winter of 1978. All 970 individuals participated in both the summer and winter surveys. The amount of tap water consumed was estimated based on the respondents' identification of the type and size of beverage container used, compared to standard-sized vessels. The survey questionnaires included a pictorial guide to help participants in classifying the sizes of the vessels. For example, a small glass of water was assumed to be equivalent to 4.0 ounces of water, and a large glass was assumed to contain 9.0 ounces of water. The study also accounted for water derived from ice cubes and popsicles, and water in soups, infant formula, and juices. The survey did not attempt to differentiate between tap water consumed at home and tap water consumed away from home. The survey also did not attempt to estimate intake rates for fluids other than tap water. Consequently, no intake rates for total fluids were reported.

Table 3-46 presents daily consumption distribution patterns for various age groups. For adults (over 18 years of age) only, the average total tap water intake rate was 1.38 L/day, and the 90th percentile rate was 2.41 L/day as determined by graphical interpolation. These data follow a lognormal distribution. Table 3-47 presents the intake data for males, females, and both sexes combined as a function of age and expressed in units of mL/kg body weight. The tap water survey did not include body weights of the participants, but the body-weight information was taken from a Canadian health survey dated 1981; it averaged 65.1 kg for males and 55.6 kg for females. Table 3-48 presents intake rates for specific age groups and seasons. The average daily total tap water intake rate for all ages and seasons combined was 1.34 L/day, and the 90th percentile rate was 2.36 L/day. The summer intake rates are nearly the same as the winter intake rates. The authors speculate that the reason for the small seasonal variation is that in Canada, even in the summer, the ambient temperature seldom exceeded 20°C, and marked increase in water consumption with high activity levels has been observed in other studies only when the ambient temperature has been higher than 20°C. Table 3-49 presents average daily total tap water intake rates as a function of the level of physical activity, as estimated subjectively. Table 3-50 presents the amounts of tap water consumed that are derived from various foods and beverages. Note that the consumption of direct "raw" tap water is almost constant across all age groups from school-age children through the oldest ages. The increase in total tap water consumption beyond school age is due to coffee and tea consumption.

This survey may be more representative of total tap water consumption than some other less comprehensive surveys because it included data for some tap water-containing items not covered by other studies (i.e., ice cubes, popsicles, and infant formula). One potential source of error in the study is that estimated intake rates were based on identification of standard vessel sizes; the accuracy of this type of survey data is not known. The cooler climate of Canada may have reduced the importance of large tap water intakes resulting from high activity levels, therefore making the study less applicable to the United States. The authors were not able to explain the surprisingly large variations between regional tap water intakes; the largest regional difference was between Ontario (1.18 L/day) and Quebec (1.55 L/day).

3.3.2.5. *Gillies and Paulin (1983)—Variability of Mineral Intakes From Drinking Water*

Gillies and Paulin (1983) conducted a study to evaluate variability of mineral intake from drinking water. A study population of 109 adults (75 females; 34 males) ranging in age from 16 to 80 years (mean age = 44 years) in New Zealand was asked to collect duplicate samples of water consumed directly from the tap or used in beverage preparation during a 24-hour period. Participants were asked to collect the samples on a day when all of the water consumed would be from their own home. Individuals were selected based on their willingness to participate and their ability to comprehend the collection procedures. The mean total tap water intake rate for this population was 1.25 (±0.39) L/day, and the 90th percentile rate was 1.90 L/day. The median total tap water intake rate (1.26 L/day) was very similar to the mean intake rate. The reported range was 0.26 to 2.80 L/day.

The advantage of these data is that they were generated using duplicate sampling techniques. Because this approach is more objective than recall methods, it may result in more accurate responses. However, these data are based on a short-term survey that may not be representative of long-term behavior, the population surveyed is small, and the procedures for selecting the survey population were not designed to be representative of the New Zealand population, and the results may not be applicable to the United States. For these reasons, the study is not regarded as a key study in this document.

3.3.2.6. *Pennington (1983)—Revision of the Total Diet Study Food List and Diets*

Based on data from the U.S. Food and Drug Administration's Total Diet Study, Pennington (1983) reported average intake rates for various foods and beverages for five age groups of the population. The Total Diet Study is conducted annually to monitor the nutrient and contaminant content of the U.S. food supply and to evaluate trends in consumption. Representative diets were developed based on 24-hour recall and 2-day diary data from the 1977-1978 USDA Nationwide Food Consumption Survey (NFCS) and 24-hour recall data from the Second National Health and Nutrition Examination Survey (NHANES II). The numbers of participants in NFCS and NHANES II were approximately 30,000 and 20,000, respectively. The diets were developed to "approximate 90% or more of the weight of the foods usually consumed" (Pennington, 1983). The source of water (bottled water as distinguished from tap water) was not stated in the Pennington study. For the purposes of this report, the consumption rates for the food categories defined by Pennington (1983) were used to calculate total fluid and total water intake rates for five age groups. Total water includes water, tea, coffee, soft drinks, and soups and frozen juices that are reconstituted with water. Reconstituted soups were assumed to be composed of 50% water, and juices were assumed to contain 75% water. Total fluids include total water in addition to milk, ready-to-use infant formula, milk-based soups, carbonated soft drinks, alcoholic beverages, and canned fruit juices. Table 3-51 presents these intake rates. Based on the average intake rates for total water for the two adult age groups, 1.04 and 1.26 L/day, the average adult intake rate is about 1.15 L/day. These rates should be more representative of the amount of source-specific water consumed than are total fluid intake rates. Because this study was designed to measure food intake, and it used both USDA 1978 data and NHANES II data, there was not necessarily a systematic attempt to define tap water intake per se, as distinguished from bottled water. For this reason, it is not considered a key tap water study in this document.

3.3.2.7. *U.S. EPA (1984)—An Estimation of the Daily Average Food Intake by Age and Sex for Use in Assessing the Radionuclide Intake of the General Population*

Using data collected by USDA in the 1977–1978 NFCS, U.S. EPA (1984) determined daily food and beverage intake levels by age to be used in assessing radionuclide intake through food consumption. Tap water, water-based drinks, and soups were identified subcategories of the total beverage category. Table 3-52 presents daily intake rates for tap water, water-based drinks, soup, and total beverages. As seen in Table 3-52, mean tap water intake for different adult age groups (age 20 years and older) ranged from 0.62 to 0.76 L/day, water-based drinks intake ranged from 0.34 to 0.69 L/day, soup intake ranged from 0.04 to 0.06 L/day, and mean total beverage intake levels ranged from 1.48 to 1.73 L/day. Total tap water intake rates were estimated by combining the average daily intakes of tap water, water-based drinks, and soups for each age group. For adults (ages 20 years and older), mean total tap water intake rates range from 1.04 to 1.47 L/day, and for children (ages <1 to 19 years), mean intake rates range from 0.19 to 0.90 L/day. The total tap water intake rates, derived by combining data on tap water, water-based drinks, and soup should be more representative of source-specific drinking water intake than the total beverage intake rates reported in this study. The chief limitation of the study is that the data were collected in 1978 and do not reflect the expected increase in the U.S. consumption of soft drinks and bottled water or changes in the diet within the last three decades. Since the data were collected for only a 3-day period, the extrapolation to chronic intake is uncertain. Also, these intake rates do not include reconstituted infant formula.

3.3.2.8. *Cantor et al. (1987)—Bladder Cancer, Drinking Water Source, and Tap Water Consumption*

The National Cancer Institute, in a population-based, case control study investigating the possible relationship between bladder cancer and drinking water, interviewed approximately 8,000 adult White individuals, 21 to 84 years of age (2,805 cases and 5,258 controls) in their homes, using a standardized questionnaire (Cantor et al., 1987). The cases and controls resided in one of five metropolitan areas (Atlanta, Detroit, New Orleans, San Francisco, and Seattle) and five States (Connecticut, Iowa, New Jersey, New Mexico, and Utah). The individuals interviewed were asked to recall the level of intake of tap water and other beverages in a typical week during the winter prior to the interview. Total beverage intake was divided into the following two components: (1) beverages derived from tap water; and (2) beverages from other sources. Tap water used in cooking foods and in ice cubes was apparently not considered. Participants also supplied information on the primary source of the water consumed (i.e., private well, community supply, bottled water, etc.). The control population was randomly selected from the general population and frequency matched to the bladder cancer case population in terms of age, sex, and geographic location of residence. The case population consisted of Whites only and had no people under the age of 21 years; 57% were over the age of 65 years. The fluid intake rates for the bladder cancer cases were not used because their participation in the study was based on selection factors that could bias the intake estimates for the general population. Based on responses from 5,258 White controls (3,892 males; 1,366 females), average tap water intake rates for a "typical" week were compiled by sex, age group, and geographic region. Table 3-53 lists these rates. The average total fluid intake rate was 2.01 L/day for men of which 70% (1.4 L/day) was derived from tap water, and 1.72 L/day for women of which 79% (1.35 L/day) was derived from tap water. Table 3-54 presents frequency distribution data for the 5,228 controls, for which the authors had information on both tap water consumption and cigarette smoking habits. These data follow a lognormal distribution having an average value of 1.30 L/day and an upper 90th percentile value of approximately 2.40 L/day. These values were determined by graphically interpolating the data of Table 3-54 after plotting it on log probability graph paper. These values represent the usual level of intake for this population of adults in the winter. Limitations associated with this data set are that the population surveyed was older than the general population and consisted exclusively of Whites. Also, the intake data are based on recall of behavior during the winter only. Extrapolation of the data to other seasons is difficult.

The authors presented data on person-years of residence with various types of water supply sources (municipal versus private, chlorinated versus non-chlorinated, and surface versus well water). Unfortunately, these data cannot be used to draw conclusions about the national average apportionment of surface versus groundwater since a large fraction (24%) of municipal water intake in this survey could not be specifically attributed to either ground or surface water.

3.3.2.9. *Ershow and Cantor (1989)—Total Water and Tap Water Intake in the U.S.: Population-Based Estimates of Quantities and Sources*

Ershow and Cantor (1989) estimated water intake rates based on data collected by the USDA 1977–1978 NFCS. The survey was conducted through interviews and diary entries. Daily intake rates for tap water and total water were calculated for various age groups for males, females, and both sexes combined. Tap water was defined as "all water from the household tap consumed directly as a beverage or used to prepare foods and beverages." Total water was defined as tap water plus "water intrinsic to foods and beverages" (i.e., water contained in purchased food and beverages). The authors showed that the age, sex, and racial distribution of the surveyed population closely matched the estimated 1977 U.S. population.

Table 3-55 presents daily total tap water intake rates, expressed as mL/day by age group. These data follow a lognormal distribution. Table 3-56 presents the same data, expressed as mL per kg body weight per day. Table 3-57 presents a summary of these tables, showing the mean, the 10th and 90th percentile intakes, expressed as both mL/day and mL/kg-day as a function of age. This shows that the mean and 90th percentile intake rates for adults (ages 20 to 65+) are approximately 1,410 mL/day and 2,280 mL/day, and for all ages, the mean and 90th percentile intake rates are 1,193 mL/day and 2,092 mL/day. Note that older adults have greater intakes than do adults between age 20 and 64, an observation bearing on the interpretation of the Cantor et al. (1987) study, which surveyed a population that was older than the national average (see Section 3.3.2.8).

Ershow and Cantor (1989) also measured total water intake for the same age groups and concluded that it averaged 2,070 mL/day for all groups combined and that tap water intake (1,190 mL/day) is 55% of the total water intake. (Table 3-58 presents the detailed intake data for various age groups). Ershow and Cantor (1989) also concluded that, for all age groups combined, the proportion of tap water consumed as drinking water, or used to prepare foods and beverages is 54, 10, and 36%, respectively. (Table 3-59 presents the detailed data on proportion of tap water consumed for various age groups). Ershow and Cantor (1989) also observed that males of all age groups had higher total water and tap water consumption rates than females; the variation of each from the combined-sexes mean was about 8%.

With respect to region of the country, the northeast states had slightly lower average tap water intake (1,200 mL/day) than the three other regions (which were approximately equal at 1,400 mL/day).

This survey has an adequately large size (26,446 individuals), and it is a representative sample of the U.S. population with respect to age distribution and residential location. The data are more than 20 years old and may not be entirely representative of current patterns of water intake, but, in general, the rates are similar to those presented in the key drinking water study in this chapter.

3.3.2.10. *Roseberry and Burmaster (1992)—Lognormal Distributions for Water Intake*

Roseberry and Burmaster (1992) fit lognormal distributions to the water intake data population-wide distributions for total fluid and total tap water intake based on proportions of the population in each age group. Their publication shows the data and the fitted lognormal distributions graphically. The mean was estimated as the zero intercept, and the standard deviation (SD) was estimated as the slope of the best-fit line for the natural logarithm of the intake rates plotted against their corresponding z-scores (Roseberry and Burmaster, 1992). Least squares techniques were used to estimate the best-fit straight lines for the transformed data. Table 3-60 presents summary statistics for the best-fit lognormal distribution. In this table, the simulated balanced population represents an adjustment to account for the difference in the age distribution of the U.S. population in 1988 from the age distribution in 1978 when Ershow and Cantor (1989) collected their data. Table 3-61 summarizes the quantiles and means of tap water intake as estimated from the best-fit distributions. The mean total tap water intake rates for the two adult populations (ages 20 to 65 years, and 65+ years) were estimated to be 1.27 and 1.34 L/day.

These intake rates were based on the data originally presented by Ershow and Cantor (1989). Consequently, the same advantages and disadvantages associated with the Ershow and Cantor (1989) study apply to this data set.

3.3.2.11. *Levy et al. (1995)—Infant Fluoride Intake From Drinking Water Added to Formula, Beverages, and Food*

Levy et al. (1995) conducted a study to determine fluoride intake by infants through drinking water and other beverages prepared with water and baby foods. The study was longitudinal and covered the ages from birth to 9 months old. A total of 192 mothers, recruited from the *post partum* wards of two hospitals in Iowa City, completed mail questionnaires and 3-day beverage and food diaries for their infants at ages 6 weeks, and 3, 6, and 9 months (Levy et al., 1995). The questionnaire addressed feeding habits, water sources and ingestion, and the use of dietary fluoride supplements during the preceding week (Levy et al., 1995). Data on the quantity of water consumed by itself or as an additive to infant formula, other beverages, or foods were obtained. In addition, the questionnaire addressed the infants' ingestion of cows' milk, breast milk, ready-to-feed (RTF) infant products (formula, juices, beverages, baby food), and table foods.

Mothers were contacted for any clarifications of missing data and discrepancies (Levy et al., 1995). Levy et al. (1995) assessed non-response bias and found no significant differences in the reported number of adults or children in the family, water sources, or family income at 3, 6, or 9 months. Table 3-62 provides the range of water ingestion from water by itself and from addition to selected foods and beverages. The percentage of infants ingesting water by itself increased from 28% at 6 weeks to 66% at 9 months, respectively, and the mean intake increased slightly over this time frame. During this time frame, the largest proportion of the infants' water ingestion (i.e., 36% at 9 months to 48% at 6 months) came from the addition of water to formula. Levy et al. (1995) noted that 32% of the infants at age 6 weeks and 23% of the infants at age 3 months did not receive any water from any of the sources studied. Levy et al. (1995) also noted that the proportion of children ingesting some water from all sources gradually increased with age.

The advantages of this study are that it provides information on water ingestion of infants starting at 6 weeks old, and the data are for water only and for water added to beverages and foods. The limitations of the study are that the sample size was small for each age group, it captured information from a select geographical location, and data were collected through self-reporting. The authors noted, however, that the 3-day diary has been shown to be a valid assessment tool. Levy et al. (1995) also stated that (1) for each time period, the ages of the infants varied by a few days to a few weeks, and are, therefore, not exact and could, at early ages, have an effect on age-specific intake patterns, and (2) the same number of infants were not available at each of the four time periods.

3.3.2.12. *USDA (1995)—Food and Nutrient Intakes by Individuals in the United States, 1 Day, 1989–1991*

USDA (1995) collected data on the quantity of "plain drinking water" and various other beverages consumed by individuals in one day during 1989 through 1991. The data were collected as part of USDA's CSFII. The data used to estimate mean per capita intake rates combined 1-day dietary recall data from three survey years: 1989, 1990, and 1991 during which 15,128 individuals supplied 1-day intake data. Individuals from all income levels in the 48 conterminous states and Washington D.C. were included in the sample. A complex 3-stage sampling design was employed, and the overall response rate for the study was 58%. To minimize the biasing effects of the low response rate and adjust for the seasonality, a series of weighting factors was incorporated into the data analysis. Table 3-63 presents the intake rates based on this study. Table 3-63 includes data for (a) "plain drinking water," which might be assumed to mean tap water directly consumed rather than bottled water; (b) coffee and tea, which might be assumed to be constituted from tap water; (c) fruit drinks and ades, which might be assumed to be reconstituted from tap water rather than canned products; and (d) the total of the three sources. With these assumptions, the mean per capita total intake of water is estimated to be 1,416 mL/day for adult males (i.e., 20 years of age and older), 1,288 mL/day for adult females (i.e., 20 years of age and older), and 1,150 mL/day for all ages and both sexes combined. Although these assumptions appear reasonable, a close reading of the definitions used by USDA (1995) reveals that the word "tap water" does not occur, and this uncertainty prevents the use of this study as a key study of tap water intake.

The advantages of using these data are that (1) the survey had a large sample size; and (2) the authors attempted to represent the general U.S. population by oversampling low-income groups and by weighting the data to compensate for low response rates. The disadvantages are that (1) the word "tap water" was not defined, and the assumptions that must be used in order to compare the data with the other tap water studies might not be valid; (2) the data collection period reflects only a 1-day intake period and may not reflect long-term drinking water intake patterns; (3) data on the percentiles of the distribution of intakes were not given; and (4) the data are almost 20 years old and may not be entirely representative of current intake patterns.

3.3.2.13. *U.S. EPA (1996)—Descriptive Statistics From a Detailed Analysis of the National Human Activity Pattern Survey (NHAPS) Responses*

The U.S. EPA collected information on the number of glasses of drinking water and juice reconstituted with tap water consumed by the general population as part of the National Human Activity Pattern Survey (NHAPS) (U.S. EPA, 1996). NHAPS was conducted between October 1992 and September 1994. Over 9,000 individuals in the 48 contiguous United States provided data on the duration and frequency of selected activities and the time spent in selected microenvironments via 24-hour diaries. Over 4,000 NHAPS respondents also provided information on the number of 8-ounce glasses of water and the number of 8-ounce glasses of juice reconstituted with water that they drank during the 24-hour survey period (see Table 3-64 and Table 3-65). The median number of glasses of tap water consumed was 1–2, and the median number of glasses of juice with tap water consumed was 1–2.

For both individuals who drank tap water and individuals who drank juices reconstituted with tap water, the number of glasses consumed in a day ranged from 1 to 20 glasses. The highest percentage of the population (37.1%) who drank tap water, consumed in the range of 3–5 glasses a day, and the highest percentage of the population (51.5%) who consumed juice reconstituted with tap water consumed 1–2 glasses in a day. Based on the assumption that each glass contained 8 ounces of water (226.4 mL), the total volume of tap water and juice with tap water consumed would range from 0.23 L/day (1 glass) to 4.5 L/day (20 glasses) for respondents who drank tap water. Using the same assumption, the volume of tap water consumed for the population who consumed 3–5 glasses would be 0.68 L/day to 1.13 L/day, and the volume of juice with tap water consumed for the population who consumed 1–2 glasses would be 0.23–0.46 L/day. Assuming that the average individual consumes 3-5 glasses of tap water plus 1–2 glasses of juice with tap water, the range of total tap water intake for this individual would range from 0.9 L/day to 1.64 L/day. These values are consistent with the average intake rates observed in other studies.

The advantages of NHAPS are that the data were collected for a large number of individuals and that the data are representative of the U.S. population. However, evaluation of drinking water intake rates was not the primary purpose of the study, and the data do not reflect the total volume of tap water consumed. In addition, using the assumptions described above, the estimated drinking water intake rates from this study are within the same ranges observed for other drinking water studies.

3.3.2.14. *Heller et al. (2000)—Water Consumption and Nursing Characteristics of Infants by Race and Ethnicity*

Heller et al. (2000) analyzed data from the 1994-1996 CSFII to evaluate racial/ethnic differences in the ingestion rates of water in children younger than 2 years old. Using data from 946 children in this age group, the mean amounts of water consumed from eight sources were determined for various racial/ethnic groups, including Black non-Hispanic, White non-Hispanic, Hispanic, and "other" (Asian, Pacific Islander, American Indian, Alaskan Native, and other non-specified racial/ethnic groups). The sources analyzed included (1) plain tap water, (2) milk and milk drinks, (3) reconstituted powdered or liquid infant formula made from drinking water, (4) ready-to-feed and other infant formula, (5) baby food, (6) carbonated beverages, (7) fruit and vegetable juices and other non-carbonated drinks, and (8) other foods and beverages. In addition, Heller et al. (2000) calculated mean plain water and total water ingestion rates for children by age, sex, region, urbanicity, and poverty category. Ages were defined as less than 12 months and 12 to 24 months. Regions were categorized as Northeast, Midwest, South, and West. The states represented by each of these regions were not reported in Heller et al. (2000). However, it is likely that these regions were defined in the same way as in Sohn et al. (2001). See Section 3.3.2.16 for a discussion on the Sohn et al. (2001) study. Urbanicity of the residence was defined as urban (i.e., being in a Metropolitan Statistical Area [MSA], suburban [outside of an MSA], or rural [being in a non-MSA]). Poverty category was derived from the poverty income ratio. In this study, a poverty income ratio was calculated by dividing the family's annual income by the federal poverty threshold for that size household. The poverty categories used were 0–1.30, 1.31 to 3.50, and greater than 3.50 times the federal poverty level (Heller et al., 2000).

Table 3-66 provides water ingestion estimates for the eight water sources evaluated, for each of the race/ethnic groups. Heller et al. (2000) reported that Black non-Hispanic children had the highest mean plain tap water intake (21 mL/kg-day), and White non-Hispanic children had the lowest mean plain tap water intake (13 mL/kg-day). The only statistically significant difference between the racial/ethnic groups was found to be in plain tap water consumption and total water consumption. Reconstituted baby formula made up the highest proportion of total water intake for all race/ethnic groups. Table 3-67 presents tap water and total water ingestion by age, sex, region, urbanicity, and poverty category. On average, children younger than 12 months of age consumed less plain tap water (11 mL/kg-day) than children aged 12–24 months (18 mL/kg-day). There were no significant differences in plain tap water consumption by sex, region, or urbanicity. Heller et al. (2000) reported a significant association between higher income and lower plain tap water consumption. For total water consumption, ingestion per kg body weight was lower for the 12–24 month-old children than for those younger than 12 months of age. Urban children consumed more plain tap water and total water than suburban and rural children. In addition, plain tap water and total water ingestion was found to decrease with increasing poverty category (i.e., higher wealth).

A major strength of the Heller et al. (2000) study is that it provides information on tap water and total water consumption by race, age, sex, region, urbanicity, and family income. The weaknesses in the CSFII data set have been discussed under Kahn and Stralka (2009) and U.S. EPA (2004) and include surveying participants for only 2 days.

3.3.2.15. *Sichert-Hellert et al. (2001)—Fifteen-Year Trends in Water Intake in German Children and Adolescents: Results of the DONALD Study*

Water and beverage consumption was evaluated by Sichert-Hellert et al. (2001) using 3-day dietary records of 733 children, ages 2 to 13 years, enrolled in the Dortmund Nutritional and Anthropometric Longitudinally Designed Study (DONALD study). The DONALD study is a cohort study, conducted in Germany, that collects data on diet, metabolism, growth, and development from healthy subjects between infancy and adulthood (Sichert-Hellert et al., 2001). Beginning in 1985, approximately 40 to 50 infants were enrolled in the study annually. Mothers of the participants were recruited in hospital maternity wards. Older children and parents of younger children were asked to keep dietary records for 3 days by recording and weighing (to the nearest 1 gram) all foods and fluids, including water, consumed.

Sichert-Hellert et al. (2001) evaluated 3,736 dietary records from 733 subjects (354 males and 379 females) collected between 1985 and 1999. Total water ingestion was defined as the sum of water content from food (intrinsic water), beverages, and oxidation. Beverages included milk, mineral water, tap water, juice, soft drinks, and coffee and tea. Table 3-68 presents the mean water ingestion rates for these different sources, as well as mean total water ingestion rates for three age ranges of children (aged 2 to 3 years, aged 4 to 8 years, and aged 9 to 13 years). According to Sichert-Hellert et al. (2001), mean total water ingestion increased with age from 1,114 mL/day in the 2- to 3-year-old subjects to 1,891 and 1,676 mL/day in 9- to 13-year-old boys and girls, respectively. However, mean total water intake per body weight decreased with age. Sichert-Hellert et al. (2001) observed that the most important source of total water ingestion was mineral water for all children, except the 2- to 3-year-olds. For these children, the most important source of total water ingestion was milk.

One of the limitations of this study is that it evaluated water and beverage consumption in German children and, as such, it may not be representative of consumption patterns of U.S. children.

3.3.2.16. *Sohn et al. (2001)—Fluid Consumption Related to Climate Among Children in the United States*

Sohn et al. (2001) investigated the relationship between fluid consumption among children aged 1 to 10 years and local climate using data from the third National Health and Nutrition Examination Survey (NHANES III, 1988–1994). Children aged 1 to 10 years who completed the 24-hour dietary interview (or proxy interview for the younger children) during the NHANES III survey were selected for the analysis. Breast-fed children were excluded from the analysis. Among 8,613 children who were surveyed, 688 (18%) were excluded due to incomplete data. A total of 7,925 eligible children remained. Since data for climatic conditions were not collected in the NHANES III survey, the mean daily maximum temperature from 1961 to 1990, averaged for the month during which the NHANES III survey was conducted, was obtained for each survey location from the U.S. Local Climate Historical Database. Of the 7,925 eligible children with complete dietary data, temperature information was derived for only 3,869 children (48.8%) since detailed information on survey location, in terms of county and state, was released only for counties with a population of more than a half million.

Sohn et al. (2001) calculated the total amount of fluid intake for each child by adding the fluid intake from plain drinking water and the fluid intake from foods and beverages other than plain drinking water provided by NHANES III. Sohn et al. (2001) identified major fluid sources as milk (and milk drinks), juice (fruit and vegetable juices and other non-carbonated drinks), carbonated drinks, and plain water. Fluid intake from sources other than these major sources was grouped into other foods and beverages. Other foods and beverages included bottled water, coffee, tea, baby food, soup, water-based beverages, and water used for dilution of food. Table 3-69 presents mean fluid ingestion rates of selected fluids for the total sample population and for the subsets of the sample population with and without temperature information. The estimated mean total fluid and plain water ingestion rates for the 3,869 children for whom temperature information was obtained are presented in Table 3-70 according to age (years), sex, race/ethnicity, poverty/income ratio, region, and urbanicity. Poverty/income ratio was defined as the ratio of the reported family income to the federal poverty level. The following categories were assigned low socioeconomic status (SES) = 0.000 to 1.300 times the poverty/income ratio; medium SES = 1.301 to 3.500 times the poverty/income level; and high SES = 3.501 or greater times the poverty/income level. Regions were as Northeast, Midwest, South, and West, as defined by the U.S. Census (see Table 3-70). Sohn et al. (2001) did not find a significant association between mean daily maximum temperature and total fluid or plain water ingestion, either before or after controlling for sex, age, SES, and race or ethnicity. However, significant associations between fluid ingestion and age, sex, socioeconomic status, and race and ethnicity were reported.

The main strength of the Sohn et al. (2001) study is the evaluation of water intake as it relates to weather data. The main limitations of this study were that northeast and western regions were over-represented since temperature data were only available for counties with populations in excess of a half million. In addition, Whites were under-represented compared to other racial or ethnic groups. Other limitations include lack of data for children from extremely cold or hot weather conditions.

3.3.2.17. *Hilbig et al. (2002)—Measured Consumption of Tap Water in German Infants and Young Children as Background for Potential Health Risk Assessment: Data of the DONALD Study*

Hilbig et al. (2002) estimated tap water ingestion rates based on 3-day dietary records of 504 German children aged 3, 6, 9, 12, 18, 24, and 36 months. The data were collected between 1990 and 1998 as part of the DONALD study. Details of data collection for the DONALD study have been provided previously under the Sichert-Hellert et al. (2001) study in Section 3.3.2.15 of this handbook. Tap water ingestion rates were calculated for three subgroups of children: (1) breast-fed infants ≤12 months of age (exclusive and partial breast-fed infants), (2) formula-fed infants ≤12 months of age (no human milk, but including weaning food), and (3) mixed-fed young children aged 18 to 36 months. Hilbig et al. (2002) defined "total tap water from household" as water from the tap consumed as a beverage or used in food preparation. "Tap water from food manufacturing" was defined as water used in industrial production of foods, and "Total Tap Water" was defined as tap water consumed from both the household and that used in manufacturing.

Table 3-71 summarizes total tap water ingestion (in mL/day and mL/kg-day) and tap water ingestion from household and manufacturing sources (in mL/kg-day) for breast-fed, formula-fed, and mixed-fed children. Mean total tap water intake was higher in formula-fed infants (53 mL/kg-day) than in breast-fed infants (17 g/kg-day) and mixed-fed young children (19 g/kg-day). Tap water from household sources constituted 66 to 97% of total tap water ingestion in the different age groups.

The major limitation of this study is that the study sample consists of families from an upper social background in Germany (Hilbig et al., 2002). Because the study was conducted in Germany, the data may not be directly applicable to the U.S. population.

3.3.2.18. *Marshall et al. (2003b)—Patterns of Beverage Consumption During the Transition Stage of Infant Nutrition*

Marshall et al. (2003b) investigated beverage ingestion during the transition stage of infant nutrition. Mean ingestion of infant formula, cows' milk, combined juice and juice drinks, water, and other beverages was estimated using a frequency questionnaire. A total of 701 children, aged 6 months through 24 months, participated in the Iowa Fluoride Study (IFS). Mothers of newborns were recruited from 1992 through 1995. The parents were sent questionnaires when the children were 6, 9, 12, 16, 20, and 24 months old. Of the 701 children, 470 returned all six questionnaires, 162 returned five, 58 returned four, and 11 returned three, with the minimum criteria being three questionnaires to be included in the data set (Marshall et al., 2003b). The questionnaire was designed to assess the type and quantity of the beverages consumed during the previous week. The validity of the questionnaire was assessed using a 3-day food diary for reference (Marshall et al., 2003b). Table 3-72 presents the percentage of subjects consuming beverages and mean daily beverage ingestion for children with returned questionnaires. Human milk ingestion was not quantified, but the percent of children consuming human milk was provided at each age category (see Table 3-72). Juice (100%) and juice drinks were not distinguished separately but categorized as juice and juice drinks. Water used to dilute beverages beyond normal dilution and water consumed alone were combined. Based on Table 3-72, 97% of the children consumed human milk, formula, or cows' milk throughout the study period, and the percentage of infants consuming human milk decreased with age, while the percent consuming water increased (Marshall et al., 2003b). Marshall et al. (2003b) observed that, in general, lower family incomes were associated with less breast-feeding and increased ingestion of other beverages.

The advantage of this study is that it provides mean ingestion data for various beverages. Limitations of the study are that it is based on samples gathered in one geographical area and may not be reflective of the general population. The authors also noted the following limitations: the parents were not asked to differentiate between 100% juice and juice drinks; the data are parent-reported and could reflect perceptions of appropriate ingestion instead of actual ingestion, and a substantial number of the infants from well educated, economically secure households dropped out during the initial phase.

3.3.2.19. *Marshall et al. (2003a)—Relative Validation of a Beverage Frequency Questionnaire in Children Aged 6 Months Through 5 Years Using 3-Day Food and Beverage Diaries*

Marshall et al. (2003a) conducted a study based on data taken from 700 children in the IFS. This study compared estimated beverage ingestion rates reported in questionnaires for the preceding week and diaries for the following week. Packets were sent periodically (every 4 to 6 months) to parents of children aged 6 weeks through 5 years of age. This study analyzed data from children, aged 6 and 12 months, and 2 and 5 years of age. Beverages were categorized as human milk, infant formula, cows' milk, juice and juice drinks, carbonated and rehydration beverages, prepared drinks (from powder) and water. The beverage questionnaire was completed by parents and summarized the average amount of each beverage consumed per day by their children. The data collection for the diaries maintained by parents included 1 weekend day and 2 weekdays and included detailed information about beverages consumed. Table 3-73 presents the mean ingestion rates of all beverages for children aged 6 and 12 months and 3 and 5 years. Marshall et al. (2003a) concluded that estimates of beverage ingestion derived from quantitative questionnaires are similar to those derived from diaries. They found that it is particularly useful to estimate ingestion of beverages consumed frequently using quantitative questionnaires.

The advantage of this study is that the survey was conducted in two different forms (questionnaire and diary), and that diaries for recording beverage ingestion were maintained by parents for 3 days. The main limitation is the lack of information regarding whether the diaries were populated on consecutive or non-consecutive days. The IFS survey participants may not be representative of the general population of the United States since participants were primarily White, and from affluent and well-educated families in one geographic region of the country.

3.3.2.20. *Skinner et al. (2004)—Transition in Infants' and Toddlers' Beverage Patterns*

Skinner et al. (2004) investigated the pattern of beverage consumption by infants and children participating in the Feeding Infants and Toddlers Study (FITS) sponsored by Gerber Products Company. The FITS is a cross-sectional study designed to collect and analyze data on feeding practices, food consumption, and usual nutrient intake of U.S. infants and toddlers (Devaney et al., 2004). It included a stratified random sample of 3,022 infants and toddlers between 4 and 24 months of age. Parents or primary caregivers of sampled infants and toddlers completed a single 24-hour dietary recall of all foods and beverages consumed by the child on the previous day by telephone interview. All recalls were completed between March and July 2002. Detailed information on data collection, coding, and analyses related to FITS is provided in Devaney et al. (2004).

Beverages consumed by FITS participants were identified as total milks (i.e., human milk, infant formulas, cows' milk, soy milk, goats' milk), 100% juices, fruit drinks, carbonated beverages, water, and "other" drinks (i.e., tea, cocoa, dry milk mixtures, and electrolyte replacement beverages). There were six age groupings in the FITS study: 4 to 6, 7 to 8, 9 to 11, 12 to 14, 15 to 18, and 19 to 24 months. Skinner et al. (2004) calculated the percentage of children in each age group consuming any amount in a beverage category and the mean amounts consumed. Table 3-74 provides the mean beverage consumption rates in mL/day for the six age categories. Skinner et al. (2004) found that some form of milk beverage was consumed by almost all children at each age; however, total milk ingestion decreased with increasing age. Water consumption also doubled with age, from 163 mL/day in children aged 4 to 6 months old to 337 mL/day in children aged 19 to 24 months old. The percentages of children consuming water increased from 34% at 4 to 6 months of age to 77% at 19 to 24 months of age.

A major strength of the Skinner et al. (2004) study is the large sample size (3,022 children). However, beverage ingestion estimates are based on 1 day of dietary recall data and human milk quantity derived from studies that weighed infants before and after each feeding to determine the quantity of human milk consumed (Devaney et al., 2004); therefore, estimates of total milk ingestion may not be accurate.

3.4. PREGNANT AND LACTATING WOMEN

3.4.1. Key Study on Pregnant and Lactating Women

3.4.1.1. *Kahn and Stralka (2008)—Estimates of Water Ingestion for Women in Pregnant, Lactating and Non-Pregnant and Non-Lactating Child Bearing Age Groups Based on USDA's 1994–1996, 1998 CSFII*

The combined 1994–1996 and 1998 CSFII data sets were analyzed to examine the ingestion of water by various segments of the U.S. population as described in Section 3.3.1.1. Kahn and Stralka (2008) provided water intake data for pregnant, lactating, and child-bearing age women. Mean and upper percentile distribution data were provided. Lactating women had an estimated per capita mean community water ingestion of 1.38 L/day, the highest water ingestion rates of any identified subpopulation. The mean consumer-only population was 1.67 L/day. Table 3-75 through Table 3-82 provide estimated drinking water intakes for pregnant and lactating women, and non-pregnant, non-lactating women aged 15–44 years old. The same advantages and disadvantages discussed in Section 3.3.1.1 apply to these data.

3.4.2. Relevant Studies on Pregnant and Lactating Women

3.4.2.1. *Ershow et al. (1991)—Intake of Tap Water and Total Water by Pregnant and Lactating Women*

Ershow et al. (1991) used data from the 1977-1978 USDA NFCS to estimate total fluid and total tap water intake among pregnant and lactating women (ages 15–49 years). Data for 188 pregnant women, 77 lactating women, and 6,201 non-pregnant, non-lactating control women were evaluated. The participants were interviewed based on 24-hour recall and then asked to record a food diary for the next 2 days. "Tap water" included tap water consumed directly as a beverage and tap water used to prepare food and tap water-based beverages. "Total water" was defined as all water from tap water and non-tap water sources, including water contained in food. Table 3-83 and Table 3-84 present estimated total fluid and total tap water intake rates for the three groups, respectively. Lactating women had the highest mean total fluid intake rate (2.24 L/day) compared with both pregnant women (2.08 L/day) and control women (1.94 L/day). Lactating women also had a higher mean total tap water intake rate (1.31 L/day) than pregnant women (1.19 L/day) and control women (1.16 L/day). The tap water distributions are neither normal nor lognormal, but lactating women had a higher mean tap water intake than controls and pregnant women. Ershow et al. (1991) also reported that rural women (N = 1,885) consumed more total water (1.99 L/day) and tap water (1.24 L/day) than urban/suburban women (N = 4,581, 1.93 and 1.13 L/day, respectively). Total water and tap water intake rates were lowest in the northeastern region of the United States (1.82 and 1.03 L/day) and highest in the western region of the United States (2.06 L/day and 1.21 L/day). Mean intake per unit body weight was highest among lactating women for both total fluid and total tap water intake. Total tap water intake accounted for over 50% of mean total fluid in all three groups of women (see Table 3-84). Drinking water accounted for the largest single proportion of the total fluid intake for control (30%), pregnant (34%), and lactating women (30%) (see Table 3-85). All other beverages combined accounted for approximately 46%, 43%, and 45% of the total water intake for control, pregnant, and lactating women, respectively. Food accounted for the remaining portion of total water intake.

The same advantages and limitations associated with the Ershow and Cantor (1989) data also apply to these data sets (see Section 3.3.2.9). A further advantage of this study is that it provides information on estimates of total water and tap water intake rates for pregnant and lactating women. This topic has rarely been addressed in the literature.

3.4.2.2. *Forssen et al. (2007)—Predictors of Use and Consumption of Public Drinking Water Among Pregnant Women*

Forssen et al. (2007) evaluated the demographic and behavioral characteristics that would be important in predicting water consumption among pregnant women in the United States. Data were collected through telephone interviews with 2,297 pregnant women in three geographical areas in the southern United States. Women 18 years old and ≤12 weeks pregnant were recruited from the local communities and from both private and public prenatal care facilities in the southern United States. Variables studied included demographic, health status and history (e.g., diabetes, pregnancy history), behavioral (e.g., exercise, smoking, caffeine consumption), and some physiological characteristics (e.g., pre-pregnancy weight). Daily amount of water ingestion was estimated based on cup sizes defined in the interview. Water consumption was reported as cold tap water (filtered and unfiltered) and bottled water. Other behavioral information on water use such as showering and bathing habits, use of swimming pools, hot tubs, and Jacuzzis was collected. The overall mean tap water ingested was 1.7 L/day (percentiles: 25^{th} = 0.5 L/day, 50^{th} = 1.4 L/day, 75^{th} = 2.4 L/day, and 90^{th} = 3.8 L/day). The overall mean bottled water ingested was 0.6 L/day (percentiles: 25^{th} = 0.1 L/day, 50^{th} = 0.2 L/day, 75^{th} = 0.6 L/day, and 90^{th} = 1.8 L/day). Table 3-86 presents water ingestion by the different variables studied, and Table 3-87 presents the percentage of ingested tap water that is filtered and unfiltered by various variables. The advantage of this study is that it investigated water consumption in relation to multiple variables. However, the study population was not random and not representative of the entire United States. There are also limitations associated with recall bias.

3.5. HIGH ACTIVITY LEVELS/HOT CLIMATES

3.5.1. Relevant Studies on High Activity Levels/Hot Climates

3.5.1.1. *McNall and Schlegel (1968)—Practical Thermal Environmental Limits for Young Adult Males Working in Hot, Humid Environments*

McNall and Schlegel (1968) conducted a study that evaluated the physiological tolerance of adult males working under varying degrees of physical activity. Subjects were required to operate pedal-driven propeller fans for 8-hour work cycles under varying environmental conditions. The activity pattern for each individual was cycled as 15 minutes of pedaling and 15 minutes of rest for each 8-hour period. Two groups of eight subjects each were used. Work rates were divided into three categories as follows: high activity level (0.15 horsepower [hp] per person), medium activity level (0.1 hp per person), and low activity level (0.05 hp per person). Evidence of physical stress (i.e., increased body temperature, blood pressure, etc.) was recorded, and individuals were eliminated from further testing if certain stress criteria were met. The amount of water consumed by the test subjects during the work cycles was also recorded. Water was provided to the individuals on request.

Table 3-88 presents the water intake rates obtained at the three different activity levels and the various environmental temperatures. The data presented are for test subjects with continuous data only (i.e., those test subjects who were not eliminated at any stage of the study as a result of stress conditions). Water intake was the highest at all activity levels when environmental temperatures were increased. The highest intake rate was observed at the low activity level at 100°F (0.65 L/hour); however, there were no data for higher activity levels at 100°F. It should be noted that this study estimated intake on an hourly basis during various levels of physical activity. These hourly intake rates cannot be converted to daily intake rates by multiplying by 24 hours/day because they are only representative of intake during the specified activity levels, and the intake rates for the rest of the day are not known. Therefore, comparison of intake rate values from this study cannot be made with values from the previously described studies on drinking water intake.

3.5.1.2. *U.S. Army (1983)—Water Consumption Planning Factors Study*

The U.S. Army has developed water consumption planning factors to enable them to transport an adequate amount of water to soldiers in the field under various conditions (U.S. Army, 1983). Both climate and activity levels were used to determine the appropriate water consumption needs. Consumption factors have been established for the following uses: (1) drinking, (2) heat treatment, (3) personal hygiene, (4) centralized hygiene, (5) food preparation, (6) laundry, (7) medical treatment, (8) vehicle and aircraft maintenance, (9) graves registration, and (10) construction. Only personal drinking water consumption factors are described here. Drinking water consumption planning factors are based on the estimated amount of water needed to replace fluids lost by urination, perspiration, and respiration. It assumes that water lost to urinary output averages 1 quart/day (0.9 L/day), and perspiration losses range from almost nothing in a controlled environment to 1.5 quarts/day (1.4 L/day) in a very hot climate where individuals are performing strenuous work. Water losses to respiration are typically very low except in extreme cold where water losses can range from 1 to 3 quarts/day (0.9 to 2.8 L/day). This occurs when the humidity of inhaled air is near zero, but expired air is 98% saturated at body temperature (U.S. Army, 1983).

Drinking water is defined by the U.S. Army (1983) as "all fluids consumed by individuals to satisfy body needs for internal water." This includes soups, hot and cold drinks, and tap water. Planning factors have been established for hot, temperate, and cold climates based on the following mixture of activities among the workforce: 15% of the force performing light work, 65% of the force performing medium work, and 20% of the force performing heavy work. Hot climates are defined as tropical and arid areas where the temperature is greater than 80°F. Temperate climates are defined as areas where the mean daily temperature ranges from 32°F to 80°F. Cold regions are areas where the mean daily temperature is less than 32°F. Table 3-89 presents drinking water consumption factors for these three climates. These factors are based on research on individuals and small unit training exercises. The estimates are assumed to be conservative because they are rounded up to account for the subjective nature of the activity mix and minor water losses that are not considered (U.S. Army, 1983).

The advantage of using these data is that they provide a conservative estimate of drinking water intake among individuals performing at various levels of physical activity in hot, temperate, and cold climates. However, the planning factors described here are based on assumptions about water loss from urination, perspiration, and respiration, and are not based on survey data or actual measurements.

3.6. WATER INGESTION WHILE SWIMMING AND DIVING

3.6.1. Key Study on Water Ingestion While Swimming

3.6.1.1. *Dufour et al. (2006)—Water Ingestion During Swimming Activities in a Pool: A Pilot Study*

Dufour et al. (2006) estimated the amount of water ingested while swimming, using cyanuric acid as an indicator of pool water ingestion exposure. Cyanuric acid is a breakdown product of chloroisocyanates, which are commonly used as disinfectant stabilizers in recreational water treatment. Because ingested cyanuric acid passes through the body unmetabolized, the volume of water ingested can be estimated based on the amount of cyanuric acid measured in the pool water and in the urine of swimmers, as follows:

$$V_{pool\ water\ ingested} = V_{urine} \times CA_{urine}/CA_{pool} \quad \text{(Eqn. 3-1)}$$

where:

$V_{pool\ water\ ingested}$	= volume of pool water ingested (mL),
V_{urine}	= volume of urine collected over a 24-hour period (mL),
CA_{urine}	= concentration of cyanuric acid in urine (mg/L), and
CA_{pool}	= concentration of cyanuric acid in pool water (mg/L).

According to Dufour et al. (2006), dermal absorption of cyanuric acid has been shown to be negligible. Thus, the concentration in urine is assumed to represent the amount ingested. Dufour et al. (2006) estimated pool water intake among 53 swimmers that participated in a pilot study at an outdoor swimming pool treated with chloroisocyanate. This pilot study population included 12 adults (4 males and 8 females) and 41 children under 18 years of age (20 males and 21 females). The study participants were asked not to swim for 24 hours before or after a 45-minute period of active swimming in the pool. Pool water samples were collected prior to the start of swimming activities, and swimmers' urine was collected for 24 hours after the swimming event ended. The pool water and urine sample were analyzed for cyanuric acid.

Table 3-90 presents the results of this pilot study. The mean volumes of water ingested over a 45-minute period were 16 mL for adults and 37 mL for children. The maximum volume of water ingested by adults was 53 mL, and by children, was 154 mL/45 minutes, as found in the recommendations table for water ingestion while swimming (see Table 3-5). The 97th percentile volume of water ingested by children was approximately 90 mL/45 minutes (see Table 3-5).

The advantage of this study is that it is one of the first attempts to measure water ingested while swimming. However, the number of study participants was low, and data cannot be broken out by the recommended age categories. As noted by Dufour et al. (2006), swimming behavior of pool swimmers may be similar to freshwater swimmers but may differ from salt water swimmers.

Based on the results of the Dufour et al. (2006) study, the recommended mean water ingestion rates for exposure scenarios involving swimming activities are 21 mL/hour for adults and 49 mL/hour for children under 18 years of age. Because the data set is limited, upper percentile water ingestion rates for swimming are based on the 97th percentile value for children and the maximum value for adults from the Dufour et al. (2006) study. These values are 71 mL/hour for adults and 120 mL/hour for children (see Table 3-5). Also, competitive swimmers may swallow more water than the recreational swimmers observed in this study (Dufour et al., 2006).

3.6.2. Relevant Studies on Water Ingestion While Swimming, Diving, or Engaging in Recreational Water Activities

3.6.2.1. *Schijven and de Roda Husman (2006)—A Survey of Diving Behavior and Accidental Occupational and Sport Divers to Assess the Risk of Infection With Waterborne Pathogenic Microorganisms*

Schijven and de Roda Husman (2006) estimated the amount of water ingested by occupational and sports divers in The Netherlands. Questionnaires were used to obtain information on the number of dives for various types of water bodies, and the approximate volume of water ingested per dive. Estimates of the amount of water ingested were made by comparing intake to common volumes (i.e., a few drops = 2.75 mL; shot glass = 25 mL; coffee cup = 100 mL; soda glass = 190 mL). The study was conducted among occupational divers in 2002 and among sports divers in 2003 and included responses from more than 500 divers. Table 3-91 provides the results of this study. On average, occupational divers ingested 9.8 mL/dive marine water and 5.7 mL/dive freshwater. Sports divers wearing an ordinary diving mask ingested 9.0 mL/dive marine water and 13 mL/dive fresh recreational water. Sports divers who wore full face masks ingested less water. The main limitation of this study is that no measurements were taken. It relies on estimates of the perceived amount of water ingested by the divers.

3.6.2.2. *Schets et al. (2011)—Exposure Assessment for Swimmers in Bathing Waters and Swimming Pools*

Schets et al. (2011) collected exposure data for swimmers in freshwater, seawater, and swimming pools in 2007 and 2009. Information on the frequency, duration, and amount of water swallowed were collected via questionnaires administered to nearly 10,000 people in The Netherlands. Individuals 15 years of age and older were considered to be adults and answered questions for themselves, and a parent answered the questions for their eldest child under 15 years of age. Survey participants estimated the amount of water that they swallowed while swimming by responding in one of four ways: (1) none or only a few drops; (2) one or two mouthfuls; (3) three to five mouthfuls; or (4) six to eight mouthfuls. Schets et al. (2011) conducted a series of experiments to measure the amount of water that corresponded to a mouthful of water and converted the data in the four response categories to volumes of water ingested. Monte Carlo analyses were used to combine the distribution of volume (i.e., mouthful) measurements with the distribution of responses in the four response categories to generate distributions of the amount of water swallowed per event for adult men and women, and children less than 15 year of age. Table 3-92 presents the means and 95% confidence intervals for the duration of swimming and amount of water ingested during swimming. Frequency data were also provided by Schets et al. (2011), but these data are not presented here because they are for the population of The Netherlands and may not be representative of swimming frequency in the U.S. According to Schets et al. (2011), the mean volume of water ingested by children (<15 years) during an average swimming pool event lasting 81 minutes was 51 mL or 0.63 mL/min (38 mL/hour). The values for children were slightly lower for swimming in freshwater and seawater. For adults, the mean volume of water ingested ranged from 0.5 to 0.6 mL/min (30 to 36 mL/hour) for men and 0.3 to 0.4 mL/min (20 to 26 mL/hour) for women (see Table 3-92).

The advantages of this study are that it is based on a relatively large sample size and that data are provided for various types of swimming environments (i.e., pools, freshwater, and seawater). However, the data were collected from a population in The Netherlands and may not be entirely representative of the United States. While the ingestion data are based primarily on self-reported estimates, the mean values reported in this study are similar to those based on measurements of cyanuric acid in the urine of swimmers as reported by Dufour et al. (2006).

3.6.2.3. *Dorevitch et al. (2011)—Water Ingestion During Water Recreation*

Dorevitch et al. (2011) estimated the volumes of water ingested during "limited contact water recreation activities." These activities included such as canoeing, fishing, kayaking, motor boating, rowing, wading and splashing, and walking. Full contact scenarios (i.e., swimming and immersion) were also evaluated. Dorevitch et al. (2011) estimated water intake among individuals greater than 6 years of age using two different methods in studies conducted in 2009. In the first surface water study, self-reported estimates of ingestion were obtained via interview from 2,705 individuals after they engaged in recreation activities in Chicago area surface waters. A total of 2,705 participants reported whether they swallowed no water, a drop or two, a teaspoon, or one or more mouthfuls of water during one of the five limited contact recreational activities (i.e., canoeing, fishing, kayaking, motor boating, and rowing). A second study was conducted in swimming pools where 662 participants engaged in limited contact scenarios (i.e., canoeing, simulated fishing, kayaking, motor boating, rowing, wading/splashing, and walking), as well as full contact activities such as swimming and immersion. Participants were interviewed after performing their water activity and reported on their estimated water ingestion. In addition, 24-hour urine samples were collected for analysis of cyanuric acid, a tracer of swimming pool water. Translation factors for each of the reported categories of ingestion (e.g., none, drop/teaspoon, mouthful) were developed using the results of the urine analyses. These translation factors were used to estimate the volume of water ingested for the various water activities evaluated in this study (Dorevitch et al., 2011). Table 3-93 presents the estimated volumes of water ingested for the limited and full contact scenarios. Swimmers had the highest estimated water intake (mean = 10 mL/hr; 95% upper confidence limit = 35 mL/hr) among the activities evaluated.

The advantage of this study is that it provides information on the estimated volume of water ingested during both limited and full contact recreational activities. However, the data are based on self-reporting, and data are not provided for individual age groups of the population.

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Table 3-7. Per Capita[a] Estimates of Combined Direct and Indirect[b] Water Ingestion Based on 1994–1996, 1998 CSFII: Community Water (mL/day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	91	184	-	-	-	322	687*	839*	860*
1 to <3 months	253	227	-	-	-	456	804	896*	1,165*
3 to <6 months	428	362	-	-	148	695	928	1,056	1,424*
6 to <12 months	714	360	-	17	218	628	885	1,055	1,511*
1 to <2 years	1,040	271	-	60	188	402	624	837	1,215*
2 to <3 years	1,056	317	-	78	246	479	683	877	1,364*
3 to <6 years	4,391	380	4	98	291	547	834	1,078	1,654
6 to <11 years	1,670	447	22	133	350	648	980	1,235	1,870*
11 to <16 years	1,005	606	30	182	459	831	1,387	1,727	2,568*
16 to <18 years	363	731	16	194	490	961	1,562	1,983*	3,720*
18 to <21 years	389	826	24	236	628	1,119	1,770	2,540*	3,889*
>21 years	9,207	1,104	69	422	928	1,530	2,230	2,811	4,523
>65 years[c]	2,170	1,127	16	545	1,067	1,601	2,139	3,551	3,661
All ages	20,607	926	30	263	710	1,311	2,014	2,544	4,242

[a] Includes all participants whether or not they ingested any water from the source during survey period.

[b] Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages.

[c] U.S. EPA (2004).

\- = Zero.

* The sample size does not meet minimum requirements as described in the "*Third Report on Nutrition Monitoring in the United States*" (FASEB/LSRO, 1995).

Source: Kahn (2008) (Based on 1994–1996, 1998 USDA CSFII).

Table 3-8. Per Capita[a] Estimates of Combined Direct and Indirect[b] Water Ingestion Based on 1994–1996, 1998 CSFII: Bottled Water (mL/day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	91	104	-	-	-	18	437*	556*	1,007*
1 to <3 months	253	106	-	-	-	-	541	771*	1,056*
3 to <6 months	428	120	-	-	-	-	572	774	1,443*
6 to <12 months	714	120	-	-	-	53	506	761	1,284*
1 to <2 years	1,040	59	-	-	-	-	212	350	801*
2 to <3 years	1,056	76	-	-	-	-	280	494	1,001*
3 to <6 years	4,391	84	-	-	-	-	325	531	1,031*
6 to <11 years	1,670	84	-	-	-	-	330	532	1,079*
11 to <16 years	1,005	111	-	-	-	-	382	709	1,431*
16 to <18 years	363	109	-	-	-	-	426	680*	1,605*
18 to <21 years	389	185	-	-	-	-	514	1,141*	2,364*
>21 years	9,207	189	-	-	-	-	754	1,183	2,129
>65 years[c]	2,170	136	-	-	-	-	591	1,038	1,957
All ages	20,607	163	-	-	-	-	592	1,059	2,007

[a] Includes all participants whether or not they ingested any water from the source during survey period.
[b] Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages.
[c] U.S. EPA (2004).
- = Zero.
* The sample size does not meet minimum requirements as described in the *Third Report on Nutrition Monitoring in the United States* (FASEB/LSRO, 1995).

Source: Kahn (2008) (Based on 1994–1996, 1998 USDA CSFII).

Table 3-9. Per Capita[a] Estimates of Combined Direct and Indirect[b] Water Ingestion Based on 1994–1996, 1998 CSFII: Other Sources (mL/day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	91	13	-	-	-	-	-	-	393*
1 to <3 months	253	35	-	-	-	-	-	367*	687*
3 to <6 months	428	45	-	-	-	-	-	365	938*
6 to <12 months	714	45	-	-	-	-	31	406	963*
1 to <2 years	1,040	22	-	-	-	-	-	118	482*
2 to <3 years	1,056	39	-	-	-	-	52	344	718*
3 to <6 years	4,391	43	-	-	-	-	58	343	830
6 to <11 years	1,670	61	-	-	-	-	181	468	1,047*
11 to <16 years	1,005	102	-	-	-	-	344	786	1,698*
16 to <18 years	363	97	-	-	-	-	295	740*	1,760*
18 to <21 years	389	47	-	-	-	-	-	246*	1,047*
>21 years	9,207	156	-	-	-	-	541	1,257	2,381
>65 years[c]	2,170	171	-	-	-	-	697	1,416	2,269
All ages	20,607	128	-	-	-	-	345	1,008	2,151

a Includes all participants whether or not they ingested any water from the source during survey period.
b Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages.
c U.S. EPA (2004).
- = Zero.
* The sample size does not meet minimum requirements as described in the *Third Report on Nutrition Monitoring in the United States* (FASEB/LSRO, 1995).

Source: Kahn (2008) (Based on 1994–1996, 1998 USDA CSFII).

Table 3-10. Per Capita[a] Estimates of Combined Direct and Indirect[b] Water Ingestion Based on 1994–1996, 1998 CSFII: All Sources (mL/day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	91	301	-	-	135	542	846*	877*	1,088*
1 to <3 months	253	368	-	-	267	694	889	1,020*	1,265*
3 to <6 months	428	528	-	89	549	812	1,025	1,303	1,509*
6 to <12 months	714	530	37	181	505	771	1,029	1,278	1,690*
1 to <2 years	1,040	358	68	147	287	477	735	961	1,281*
2 to <3 years	1,056	437	104	211	372	588	825	999	1,662*
3 to <6 years	4,391	514	126	251	438	681	980	1,200	1,794
6 to <11 years	1,670	600	169	304	503	803	1,130	1,409	2,167*
11 to <16 years	1,005	834	224	401	663	1,099	1,649	1,960	3,179*
16 to <18 years	363	964	236	387	742	1,273	1,842	2,344*	3,854*
18 to <21 years	389	1,075	189	406	803	1,394	2,117	2,985*	4,955*
>21 years	9,207	1,466	500	828	1,278	1,871	2,553	3,195	5,174
>65 years[c]	2,170	1,451	651	935	1,344	1,832	2,323	2,708	3,747
All ages	20,607	1,233	285	573	1,038	1,633	2,341	2,908	4,805

a Includes all participants whether or not they ingested any water from the source during survey period.
b Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages.
c U.S. EPA (2004).
- = Zero.
* The sample size does not meet minimum requirements as described in the *Third Report on Nutrition Monitoring in the United States* (FASEB/LSRO, 1995).

Source: Kahn (2008) (Based on 1994–1996, 1998 USDA CSFII).

Table 3-11. Per Capita[a] Estimates of Combined Direct and Indirect[b] Water Ingestion Based on 1994–1996, 1998 CSFII: Community Water (mL/kg-day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	88	52	-	-	-	101	196*	232*	253*
1 to <3 months	245	48	-	-	-	91	151	205*	310*
3 to <6 months	411	52	-	-	20	98	135	159	216*
6 to <12 months	678	41	-	2	24	71	102	126	185*
1 to <2 years	1,002	23	-	5	17	34	53	71	106*
2 to <3 years	994	23	-	6	17	33	50	60	113*
3 to <6 years	4,112	22	-	6	17	31	48	61	93
6 to <11 years	1,553	16	1	5	12	22	34	43	71*
11 to <16 years	975	12	1	4	9	16	25	34	54*
16 to <18 years	360	11	-	3	8	15	23	31*	55*
18 to <21 years	383	12	1	4	10	16	17	35*	63*
>21 years	9,049	15	1	6	12	21	31	39	62
>65 years[c]	2,139	16	-	7	15	23	31	37	52
All ages	19,850	16	1	5	12	21	32	43	75

[a] Includes all participants whether or not they ingested any water from the source during survey period.
[b] Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages.
[c] U.S. EPA (2004).
\- = Zero.
* The sample size does not meet minimum requirements as described in the "*Third Report on Nutrition Monitoring in the United States*" (FASEB/LSRO, 1995).

Source: Kahn (2008) (Based on 1994–1996, 1998 USDA CSFII).

Table 3-12. Per Capita[a] Estimates of Combined Direct and Indirect[b] Water Ingestion Based on 1994–1996, 1998 CSFII: Bottled Water (mL/kg-day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	88	33	-	-	-	6	131*	243*	324*
1 to <3 months	245	22	-	-	-	-	97	161*	242*
3 to <6 months	411	16	-	-	-	-	74	117	193*
6 to <12 months	678	13	-	-	-	4	52	87	139*
1 to <2 years	1,002	5	-	-	-	-	18	28	67*
2 to <3 years	994	5	-	-	-	-	19	35	84*
3 to <6 years	4,112	5	-	-	-	-	18	30	59
6 to <11 years	1,553	3	-	-	-	-	10	18	41*
11 to <16 years	975	2	-	-	-	-	8	14	26*
16 to <18 years	360	2	-	-	-	-	6	10*	27*
18 to <21 years	383	3	-	-	-	-	8	19*	34*
>21 years	9.049	3	-	-	-	-	10	17	32
>65 years[c]	2,139	2	-	-	-	-	9	15	27
All ages	19,850	3	-	-	-	-	10	18	39

[a] Includes all participants whether or not they ingested any water from the source during survey period.

[b] Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages.

[c] U.S. EPA (2004).

\- = Zero.

* The sample size does not meet minimum requirements as described in the *Third Report on Nutrition Monitoring in the United States* (FASEB/LSRO, 1995).

Source: Kahn (2008) (Based on 1994–1996, 1998 USDA CSFII).

Table 3-13. Per Capita[a] Estimates of Combined Direct and Indirect[b] Water Ingestion Based on 1994–1996, 1998 CSFII: Other Sources (mL/kg-day)									
Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	88	4	-	-	-	-	-	-	122*
1 to <3 months	245	7	-	-	-	-	-	52*	148*
3 to <6 months	411	7	-	-	-	-	-	55	155*
6 to <12 months	678	5	-	-	-	-	3	35	95*
1 to <2 years	1,002	2	-	-	-	-	-	11	45*
2 to <3 years	994	3	-	-	-	-	4	23	61*
3 to <6 years	4,112	2	-	-	-	-	3	19	48
6 to <11 years	1,553	2	-	-	-	-	7	16	36*
11 to <16 years	975	2	-	-	-	-	7	14	34*
16 to <18 years	360	2	-	-	-	-	5	11*	27*
18 to <21 years	383	1	-	-	-	-	-	4*	14*
>21 years	9,049	2	-	-	-	-	7	17	33
>65 years[c]	2,139	2	-	-	-	-	10	20	35
All ages	19,850	2	-	-	-	-	6	16	35

[a] Includes all participants whether or not they ingested any water from the source during survey period.
[b] Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages.
[c] U.S. EPA (2004).
- = Zero.
* The sample size does not meet minimum requirements as described in the *Third Report on Nutrition Monitoring in the United States* (FASEB/LSRO, 1995).

Source: Kahn (2008) (Based on 1994–1996, 1998 USDA CSFII).

Table 3-14. Per Capita[a] Estimates of Combined Direct and Indirect[b] Water Ingestion Based on 1994–1996, 1998 CSFII: All Sources (mL/kg-day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	88	89	-	-	21	168	235*	269*	338*
1 to <3 months	245	77	-	-	46	134	173	246*	336*
3 to <6 months	411	75	-	9	73	118	156	186	225*
6 to <12 months	678	59	4	20	53	86	118	148	194*
1 to <2 years	1,002	31	6	13	24	39	63	85	122*
2 to <3 years	994	31	7	15	26	41	59	73	130*
3 to <6 years	4,112	29	7	14	25	38	56	69	102
6 to <11 years	1,553	21	6	10	18	27	39	50	76*
11 to <16 years	975	16	4	8	13	20	31	39	60*
16 to <18 years	360	15	4	6	12	18	28	37*	59*
18 to <21 years	383	16	3	6	12	21	32	41*	73*
>21 years	9,049	20	7	11	17	26	36	44	68
>65 years[c]	2,139	21	9	13	19	27	34	39	54
All ages	20,850	21	6	10	17	26	38	50	87

a Includes all participants whether or not they ingested any water from the source during survey period.
b Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages.
c U.S. EPA (2004).
- = Zero.
* The sample size does not meet minimum requirements as described in the *Third Report on Nutrition Monitoring in the United States* (FASEB/LSRO, 1995).

Source: Kahn (2008) (Based on 1994–1996, 1998 USDA CSFII).

Table 3-15. Consumer-Only[a] Estimates of Combined Direct and Indirect[b] Water Ingestion Based on 1994–1996, 1998 CSFII: Community Water (mL/day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	40	470*	32*	215*	482*	692*	849*	858*	919*
1 to <3 months	114	552	67*	339	533	801	943*	1,053*	1,264*
3 to <6 months	281	556	44	180	561	837	1,021	1,171*	1,440*
6 to <12 months	562	467	44	105	426	710	971	1,147	1,586*
1 to <2 years	916	308	43	107	229	428	674	893	1,248*
2 to <3 years	934	356	49	126	281	510	700	912	1,388*
3 to <6 years	3,960	417	57	146	336	581	867	1,099	1,684
6 to <11 years	1,555	480	74	177	373	682	994	1,251	2,024*
11 to <16 years	937	652	106	236	487	873	1,432	1,744	2,589*
16 to <18 years	341	792	106	266	591	987	1,647	2,002*	3,804*
18 to <21 years	364	895	114	295	674	1,174	1,860	2,565*	3,917*
>21 years	8,505	1,183	208	529	1,006	1,582	2,289	2,848	4,665
>65 years[c]	1,958	1,242	310	704	1,149	1,657	2,190	2,604	3,668
All ages	18,509	1,000	127	355	786	1,375	2,069	2,601	4,274

[a] Excludes individuals who did not ingest water from the source during the survey period.
[b] Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages.
[c] U.S. EPA (2004).
* The sample size does not meet minimum requirements as described in the "*Third Report on Nutrition Monitoring in the United States*" (FASEB/LSRO, 1995).

Source: Kahn (2008) (Based on 1994–1996, 1998 USDA CSFII).

Table 3-16. Consumer-Only[a] Estimates of Combined Direct and Indirect[b] Water Ingestion Based on 1994–1996, 1998 CSFII: Bottled Water (mL/day)

Age	Sample size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	25	-	-	-	-	-	-	-	-
1 to <3 months	64	450*	31*	62*	329*	743*	886*	1,045*	1,562*
3 to <6 months	103	507	48*	88	493	747	1,041*	1,436*	1,506*
6 to <12 months	200	425	47	114	353	630	945*	1,103*	1,413*
1 to <2 years	229	262	45	88	188	324	600	709*	1,083*
2 to <3 years	232	352	57	116	241	471	736	977*	1,665*
3 to <6 years	1,021	380	72	149	291	502	796	958	1,635*
6 to <11 years	332	430	88	168	350	557	850	1,081*	1,823*
11 to <16 years	192	570	116*	229	414	719	1,162*	1,447*	2,705*
16 to <18 years	63	615*	85*	198*	446*	779*	1,365*	1,613*	2,639*
18 to <21 years	97	769	118*	236	439	943	1,788*	2,343*	3,957*
>21 years	1,893	831	167	354	650	1,071	1,773	2,093	3,505
>65 years[c]	302	910	234	465	785	1,182	1,766	2,074	2,548
All ages	4,451	736	118	266	532	975	1,567	1,964	3,312

[a] Excludes individuals who did not ingest water from the source during the survey period.

[b] Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages.

[c] U.S. EPA (2004).

\- Insufficient sample size to estimate mean and percentiles.

* The sample size does not meet minimum requirements as described in the *Third Report on Nutrition Monitoring in the United States* (FASEB/LSRO, 1995).

Source: Kahn (2008) (Based on 1994–1996, 1998 USDA CSFII).

Table 3-17. Consumer-Only[a] Estimates of Combined Direct and Indirect[b] Water Ingestion Based on 1994–1996, 1998 CSFII: Other Sources (mL/day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	3	-	-	-	-	-	-	-	-
1 to <3 months	19	-	-	-	-	-	-	-	-
3 to <6 months	38	562*	59*	179*	412*	739*	983*	1,205*	2,264*
6 to <12 months	73	407*	31*	121*	300*	563*	961*	1,032*	1,144*
1 to <2 years	98	262	18*	65	143	371	602*	899*	1,204*
2 to <3 years	129	354	56*	134	318	472	704*	851*	1,334*
3 to <6 years	533	396	59	148	314	546	796	1,019	1,543*
6 to <11 years	219	448	89	177	347	682	931	1,090*	1,596*
11 to <16 years	151	687	171*	296	482	947	1,356*	1,839*	2,891*
16 to <18 years	53	657*	152*	231*	398*	823*	1,628*	1,887*	2,635*
18 to <21 years	33	569*	103*	142*	371*	806*	1,160*	1,959*	1,962*
>21 years	1,386	1,137	236	503	976	1,533	2,161	2,739	4,673
>65 years[c]	323	1,259	360	680	1,188	1,660	2,136	2,470	3,707*
All ages	2,735	963	148	347	741	1,344	1,970	2,468	3,814

[a] Excludes individuals who did not ingest water from the source during the survey period.
[b] Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages.
[c] U.S. EPA (2004).
- Insufficient sample size to estimate means and percentiles.
* The sample size does not meet minimum requirements as described in the *Third Report on Nutrition Monitoring in the United States* (FASEB/LSRO, 1995).

Source: Kahn (2008) (Based on 1994–1996, 1998 USDA CSFII).

Table 3-18. Consumer-Only[a] Estimates of Combined Direct and Indirect[b] Water Ingestion Based on 1994–1996, 1998 CSFII: All Sources (mL/day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	58	511*	51*	266*	520*	713*	858*	986*	1,274*
1 to <3 months	178	555	68*	275	545	801	946*	1,072*	1,470*
3 to <6 months	363	629	69	384	612	851	1,064	1,330*	1,522*
6 to <12 months	667	567	90	250	551	784	1,050	1,303	1,692*
1 to <2 years	1,017	366	84	159	294	481	735	978	1,281*
2 to <3 years	1,051	439	105	213	375	589	825	1,001	1,663*
3 to <6 years	4,350	518	134	255	442	682	980	1,206	1,796
6 to <11 years	1,659	603	177	310	506	805	1,131	1,409	2,168*
11 to <16 years	1,000	837	229	404	665	1,105	1,649	1,961	3,184*
16 to <18 years	357	983	252	395	754	1,276	1,865	2,346*	3,866*
18 to <21 years	383	1,094	219	424	823	1,397	2,144	3,002*	4,967*
>21 years	9,178	1,472	506	829	1,282	1,877	2,559	3,195	5,175
>65 years[c]	2,167	1,453	651	939	1,345	1,833	2,324	2,708	3,750
All ages	20,261	1,242	296	585	1,047	1,642	2,345	2,923	4,808

[a] Excludes individuals who did not ingest water from the source during the survey period.

[b] Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages.

[c] U.S. EPA (2004).

* The sample size does not meet minimum requirements as described in the *Third Report on Nutrition Monitoring in the United States* (FASEB/LSRO, 1995).

Source: Kahn (2008) (Based on 1994–1996, 1998 USDA CSFII).

Table 3-19. Consumer-Only[a] Estimates of Direct and Indirect[b] Water Ingestion Based on 1994–1996, 1998 CSFII: Community Water (mL/kg-day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	37	137*	11*	65*	138*	197*	235*	238*	263*
1 to <3 months	108	119	12*	71	107	151	228*	285*	345*
3 to <6 months	269	80	7	27	77	118	148	173*	222*
6 to <12 months	534	53	5	12	47	81	112	129	186*
1 to <2 years	880	27	4	9	20	36	56	75	109*
2 to <3 years	879	26	4	9	21	36	52	62	121*
3 to <6 years	3,703	24	3	8	19	33	49	65	97
6 to <11 years	1,439	17	3	6	13	23	35	45	72*
11 to <16 years	911	13	2	5	10	17	26	34	54*
16 to <18 years	339	12	1	4	9	16	24	32*	58*
18 to <21 years	361	13	2	5	10	17	29	35*	63*
>21 years	8,355	16	3	7	13	22	32	39	63
>65 years[c]	1,927	18	5	10	16	24	32	37	53
All ages	17,815	17	3	7	13	22	33	44	77

a Excludes individuals who did not ingest water from the source during the survey period.
b Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages.
c U.S. EPA (2004).
* The sample size does not meet minimum requirements as described in the *Third Report on Nutrition Monitoring in the United States* (FASEB/LSRO, 1995).

Source: Kahn (2008) (Based on 1994–1996, 1998 USDA CSFII).

Table 3-20. Consumer-Only[a] Estimates of Direct and Indirect[b] Water Ingestion Based on 1994–1996, 1998 CSFII: Bottled Water (mL/kg-day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	25	-	-	-	-	-	-	-	-
1 to <3 months	64	92*	7*	12*	76*	151*	164*	220*	411*
3 to <6 months	95	72	6*	15	69	100	149*	184*	213*
6 to <12 months	185	47	5*	11	34	73	104*	120*	166*
1 to <2 years	216	22	5	8	16	27	49	66*	103*
2 to <3 years	211	25	4	8	17	35	54	81*	91*
3 to <6 years	946	21	4	8	16	29	45	57	90*
6 to <11 years	295	15	3	5	11	19	30	42*	69*
11 to <16 years	180	11	2*	4	8	14	24*	27*	44*
16 to <18 years	63	10*	1*	3*	7*	11*	23*	27*	37*
18 to <21 years	93	11	2*	3	6	14	27*	30*	54*
>21 years	1,861	12	2	5	9	16	25	31	45
>65 years[c]	297	13	3	7	12	17	26	30	42*
All ages	4,234	13	2	5	9	17	27	36	72

[a] Excludes individuals who did not ingest water from the source during the survey period.
[b] Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages.
[c] U.S. EPA (2004).
\- Insufficient sample size to estimate means and percentiles.
* The sample size does not meet minimum requirements as described in the *Third Report on Nutrition Monitoring in the United States* (FASEB/LSRO, 1995).

Source: Kahn (2008) (Based on 1994–1996, 1998 USDA CSFII).

Table 3-21. Consumer-Only[a] Estimates of Direct and Indirect[b] Water Ingestion Based on 1994–1996, 1998 CSFII: Other Sources (mL/kg-day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	3	-	-	-	-	-	-	-	-
1 to <3 months	19	-	-	-	-	-	-	-	-
3 to <6 months	38	80*	10*	23*	59*	106*	170*	200*	246*
6 to <12 months	68	44*	4*	10*	33*	65*	95*	106*	147*
1 to <2 years	95	23	1*	5	13	28	46*	84*	125*
2 to <3 years	124	26	4*	10	21	34	55*	66*	114*
3 to <6 years	505	22	3	8	17	30	46	56	79*
6 to <11 years	208	16	3	6	12	23	32	39*	62*
11 to <16 years	148	13	3*	6	9	18	27*	36*	56*
16 to <18 years	52	10*	2*	4*	7*	12*	24*	29*	43*
18 to <21 years	33	8*	1*	2*	6*	10*	16*	27*	31*
>21 years	1,365	15	3	6	13	21	30	39	58
>65 years[c]	322	18	5	9	16	24	31	37	50*
All ages	2,657	16	3	6	12	21	32	41	67

a Excludes individuals who did not ingest water from the source during the survey period.

b Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages.

c U.S. EPA (2004).

- Indicates insufficient sample size to estimate distribution percentiles.

* The sample size does not meet minimum requirements as described in the *Third Report on Nutrition Monitoring in the United States* (FASEB/LSRO, 1995).

Source: Kahn (2008) (Based on 1994–1996, 1998 USDA CSFII).

Table 3-22. Consumer-Only[a] Estimates of Direct and Indirect[b] Water Ingestion Based on 1994–1996, 1998 CSFII: All Sources (mL/kg-day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	55	153*	13*	83*	142*	208*	269*	273*	400*
1 to <3 months	172	116	12*	50	107	161	216*	291*	361*
3 to <6 months	346	90	9	52	86	125	161	195*	233*
6 to <12 months	631	63	10	27	58	88	120	152	198*
1 to <2 years	980	31	7	14	25	40	64	86	122*
2 to <3 years	989	31	7	15	27	41	59	73	130*
3 to <6 years	4,072	29	7	15	25	38	56	70	102*
6 to <11 years	1,542	21	6	10	18	27	39	50	76*
11 to <16 years	970	16	4	8	13	20	31	39	60*
16 to <18 years	354	15	4	7	12	18	29	37*	60*
18 to <21 years	378	16	3	6	12	21	32	41*	73*
>21 years	9,020	20	7	11	17	26	36	44	68
>65 years[c]	2,136	21	9	13	19	27	34	39	54
All ages	19,509	21	6	11	17	26	38	50	87

a Excludes individuals who did not ingest water from the source during the survey period.

b Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages.

c U.S. EPA (2004).

* The sample size does not meet minimum requirements as described in the *Third Report on Nutrition Monitoring in the United States* (FASEB/LSRO, 1995).

Source: Kahn (2008) (Based on 1994–1996, 1998 USDA CSFII).

Table 3-23. Per Capita[a] Estimates of Combined Direct and Indirect[b] Water Ingestion Based on NHANES 2003–2006: Community Water (mL/day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	88	239*	-	-	78*	473*	693*	851*	956*
1 to <3 months	143	282*	-	-	41*	524*	784*	962*	1,102*
3 to <6 months	244	373*	-	-	378*	630*	794*	925*	1,192*
6 to <12 months	466	303	-	46	199	520	757*	866*	1,150*
1 to <2 years	611	223	-	27	134	310	577*	760*	1,206*
2 to <3 years	571	265	-	39	160	387	657*	861*	1,354*
3 to <6 years	1,091	327	-	67	245	465	746	959	1,570*
6 to <11 years	1,601	414	-	64	297	598	1,000	1,316	2,056*
11 to <16 years	2,396	520	-	60	329	688	1,338	1,821	2,953
16 to <18 years	1,087	573	-	59	375	865	1,378	1,783	3,053
18 to <21 years	1,245	681	-	88	355	872	1,808	2,368	3,911
≥21 years	8,673	1,043	-	227	787	1,577	2,414	2,958	4,405
≥65 years	2,287	1,046	-	279	886	1,587	2,272	2,730	4,123
All ages	18,216	869	-	134	560	1,299	2,170	2,717	4,123

[a] Includes all participants whether or not they ingested any water from the source during survey period.
[b] Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages.
- = Zero.
* Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993).

Source: U.S. EPA analysis of NHANES 2003–2006 data.

Table 3-24. Per Capita[a] Estimates of Combined Direct[b] Water Ingestion Based on NHANES 2003–2006: Bottled Water (mL/day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	88	6*	-	-	-	-	8*	28*	59*
1 to <3 months	143	21*	-	-	-	-	46*	122*	336*
3 to <6 months	244	12*	-	-	-	-	27*	77*	184*
6 to <12 months	466	34	-	-	-	26	118*	187*	422*
1 to <2 years	611	65	-	-	-	82	230*	342*	586*
2 to <3 years	571	95	-	-	-	81	303*	575*	1,136*
3 to <6 years	1,091	108	-	-	-	118	355	526	883*
6 to <11 years	1,601	138	-	-	-	172	444	696	1,138*
11 to <16 years	2,396	202	-	-	-	259	612	938	1,630
16 to <18 years	1,087	339	-	-	-	428	1,063	1,545	2,772
18 to <21 years	1,245	391	-	-	-	497	1,174	1,697	2,966
≥21 years	8,673	375	-	-	-	518	1,199	1,718	3,004
≥65 years	2,287	152	-	-	-	9	533	948	2,288
All ages	18,216	321	-	-	-	399	1,065	1,502	2,811

a Includes all participants whether or not they ingested any water from the source during survey period.

b Direct water is defined as water ingested directly as a beverage; indirect water, defined as water added in the preparation of food or beverages, was not accounted for in the estimation of bottled water intake.

\- = Zero.

* Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993).

Source: U.S. EPA analysis of NHANES 2003–2006 data.

Table 3-25. Per Capita[a] Estimates of Combined Direct and Indirect[b] Water Ingestion Based on NHANES 2003–2006: Other Sources (mL/day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	88	51*	-	-	-	92*	166*	229*	265*
1 to <3 months	143	82*	-	-	-	146*	243*	276*	544*
3 to <6 months	244	141*	-	-	75*	211*	274*	329*	1,045*
6 to <12 months	466	124	-	-	15	173	297*	770*	1,078*
1 to <2 years	611	82	-	-	5	50	271*	479*	867*
2 to <3 years	571	74	-	-	-	45	232*	459*	935*
3 to <6 years	1,091	62	-	-	-	38	179	433	883*
6 to <11 years	1,601	108	-	-	-	66	386	659	1,112*
11 to <16 years	2,396	163	-	-	-	94	495	1,030	2,242
16 to <18 years	1,087	201	-	-	-	105	603	1,231	2,581
18 to <21 years	1,245	167	-	-	-	72	432	1,154	2,474
≥21 years	8,673	282	-	-	-	151	972	1,831	3,289
≥65 years	2,287	301	-	-	-	186	1,248	1,765	2,645
All ages	18,216	237	-	-	-	123	747	1,480	3,095

a Includes all participants whether or not they ingested any water from the source during survey period.

b Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages. Does not include indirect consumption of bottled water.

- = Zero.

* Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993).

Source: U.S. EPA analysis of NHANES 2003–2006 data.

Table 3-26. Per Capita[a] Estimates of Combined Direct and Indirect[b] Water Ingestion Based on NHANES 2003–2006: All Sources (mL/day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	88	295*	-	-	104*	504*	852*	954*	1,043*
1 to <3 months	143	385*	-	-	169*	732*	1,049*	1,084*	1,265*
3 to <6 months	244	527*	-	24*	567*	889*	1,045*	1,192*	1,390*
6 to <12 months	466	461	50	124	379	761	995*	1,126*	1,521*
1 to <2 years	611	370	65	172	297	493	762*	912*	1,414*
2 to <3 years	571	435	88	190	340	585	920*	1,086*	1,447*
3 to <6 years	1,091	498	115	249	432	659	925	1,181	1,787*
6 to <11 years	1,601	660	144	335	573	870	1,184	1,567	2,302*
11 to <16 years	2,396	885	178	375	687	1,147	1,821	2,595	3,499
16 to <18 years	1,087	1,113	239	441	951	1,512	2,289	2,652	3,781
18 to <21 years	1,245	1,240	163	496	945	1,740	2,569	3,346	4,955
≥21 years	8,673	1,700	491	922	1,509	2,257	3,085	3,727	5,252
≥65 years	2,287	1,498	566	896	1,359	1,922	2,582	3,063	4,126
All ages	18,216	1,426	281	607	1,201	1,967	2,836	3,412	4,943

[a] Includes all participants whether or not they ingested any water from the source during survey period.
[b] Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages. Does not include indirect consumption of bottled water.
- = Zero.
* Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993).

Source: U.S. EPA analysis of NHANES 2003–2006 data.

Table 3-27. Per Capita[a] Estimates of Combined Direct and Indirect[b] Water Ingestion Based on NHANES 2003–2006, Mean Confidence Intervals and Bootstrap Intervals for 90th and 95th Percentiles: All Sources (mL/day)

Age	Sample Size	Mean			90th percentile			95th percentile		
			90% CI			90% BI			90% BI	
		Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound
Birth to <1 month	88	295*	208*	382*	852*	635*	941*	954*	759*	1,037*
1 to <3 months	143	385*	325*	444*	1,049*	929*	1,074*	1,084*	1,036*	1,099*
3 to <6 months	244	527*	466*	588*	1,045*	1,023*	1,126*	1,190*	1,088*	1,250*
6 to <12 months	466	461	417	506	995*	903*	1,057*	1,126*	1,056*	1,212*
1 to <2 years	611	370	339	401	762*	673*	835*	912*	838*	1,084*
2 to <3 years	571	435	397	472	920*	836*	987*	1,086*	973*	1,235*
3 to <6 years	1,091	498	470	526	925	888	1,009	1,181	1,068	1,250
6 to <11 years	1,601	660	617	703	1,184	1,117	1,294	1,567	1,411	1,810
11 to <16 years	2,396	885	818	952	1,821	1,678	2,114	2,595	2,280	2,807
16 to <18 years	1,087	1,113	1,027	1,199	2,289	2,055	2,412	2,652	2,502	2,868
18 to <21 years	1,245	1,240	1,128	1,352	2,569	2,377	2,991	3,346	3,044	3,740
≥21 years	8,673	1,700	1,641	1,759	3,085	3,027	3,147	3,727	3,586	3,858
≥65 years	2,287	1,498	1,442	1,555	2,582	2,470	2,671	3,063	2,961	3,328
All ages	18,216	1,426	1,377	1,474	2,836	2,781	2,896	3,412	3,352	3,499

a Includes all participants whether or not they ingested any water from the source during survey period.
b Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages. Does not include indirect consumption of bottled water.
* Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993).
CI = Confidence Interval.
BI = Bootstrap Interval.

Source: U.S. EPA analysis of NHANES 2003–2006 data.

Table 3-28. Per Capita[a] Estimates of Combined Direct and Indirect[b] Water Ingestion Based on NHANES 2003–2006: Community Water (mL/kg-day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	88	52*	-	-	16*	94*	144*	169*	210*
1 to <3 months	143	49*	-	-	5*	92*	134*	164*	200*
3 to <6 months	244	52*	-	-	53*	85*	116*	132*	177*
6 to <12 months	466	34	-	5	21	56	85*	103*	133*
1 to <2 years	611	20	-	2	12	28	53*	67*	115*
2 to <3 years	571	19	-	3	12	27	48*	61*	102*
3 to <6 years	1,091	18	-	4	13	27	41	51	81*
6 to <11 years	1,601	14	-	2	9	20	32	43	75*
11 to <16 years	2,396	10	-	1	6	13	23	32	61
16 to <18 years	1,087	9	-	1	6	12	20	28	44
18 to <21 years	1,245	9	-	1	5	13	23	35	53
≥21 years	8,673	13	-	3	10	20	32	40	61
≥65 years	2,287	14	-	4	12	21	32	40	59
All ages	18,216	14	-	2	9.4	19	32	42	72

a Includes all participants whether or not they ingested any water from the source during survey period.
b Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages.
\- = Zero.
* Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993).

Source: U.S. EPA analysis of NHANES 2003–2006 data.

Table 3-29. Per Capita[a] Estimates of Combined Direct[b] Water Ingestion Based on NHANES 2003–2006: Bottled Water (mL/kg-day)									
Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	88	1*	-	-	-	-	1*	7*	18*
1 to <3 months	143	4*	-	-	-	-	8*	19*	60*
3 to <6 months	244	2*	-	-	-	-	4*	11*	24*
6 to <12 months	466	4	-	-	-	3	13*	22*	42*
1 to <2 years	611	6	-	-	-	7	20*	30*	49*
2 to <3 years	571	7	-	-	-	6	21*	40*	77*
3 to <6 years	1,091	6	-	-	-	7	19	31	53*
6 to <11 years	1,601	4	-	-	-	5	13	24	38*
11 to <16 years	2,396	4	-	-	-	5	11	17	25
16 to <18 years	1,087	5	-	-	-	6	16	24	42
18 to <21 years	1,245	5	-	-	-	7	17	24	45
≥21 years	8,673	5	-	-	-	7	15	22	39
≥65 years	2,287	2	-	-	-	0	7	13	29
All ages	18,216	5	-	-	-	6	15	22	40

[a] Includes all participants whether or not they ingested any water from the source during survey period.

[b] Direct water is defined as water ingested directly as a beverage; indirect water, defined as water added in the preparation of food or beverages, was not accounted for in the estimation of bottled water intake.

\- = Zero.

* Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993).

Source: U.S. EPA analysis of NHANES 2003–2006 data.

Table 3-30. Per Capita[a] Estimates of Combined Direct and Indirect[b] Water Ingestion Based on NHANES 2003–2006: Other Sources (mL/kg-day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	88	11*	-	-	-	22*	34*	45*	53*
1 to <3 months	143	14*	-	-	-	30*	39*	49*	81*
3 to <6 months	244	20*	-	-	9*	29*	44*	60*	142*
6 to <12 months	466	14	-	-	2	18	35*	74*	137*
1 to <2 years	611	7	-	-	1	5	24*	43*	75*
2 to <3 years	571	6	-	-	-	3	17*	34*	69*
3 to <6 years	1,091	3	-	-	-	2	11	22	47*
6 to <11 years	1,601	4	-	-	-	2	13	23	42*
11 to <16 years	2,396	3	-	-	-	2	9	16	35
16 to <18 years	1,087	3	-	-	-	1	9	19	32
18 to <21 years	1,245	2	-	-	-	1	5	15	34
≥21 years	8,673	4	-	-	-	2	12	23	45
≥65 years	2,287	4	-	-	-	3	17	23	37
All ages	18,216	4	-	-	-	2	12	23	45

[a] Includes all participants whether or not they ingested any water from the source during survey period.
[b] Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages. Does not include indirect consumption of bottled water.
- = Zero.
* Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993).

Source: U.S. EPA analysis of NHANES 2003–2006 data.

Table 3-31. Per Capita[a] Estimates of Combined Direct and Indirect[b] Water Ingestion Based on NHANES 2003–2006: All Sources (mL/kg-day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	88	65*	-	-	19*	120*	173*	195*	247*
1 to <3 months	143	67*	-	-	29*	123*	180*	194*	230*
3 to <6 months	244	74*	-	4*	72*	116*	153*	179*	228*
6 to <12 months	466	52	6	14	42	84	113*	137*	181*
1 to <2 years	611	33	6	15	26	44	68*	80*	122*
2 to <3 years	571	32	6	15	25	42	67*	78*	123*
3 to <6 years	1,091	27	7	13	23	36	52	63	96*
6 to <11 years	1,601	22	5	11	18	28	42	52	78*
11 to <16 years	2,396	16	3	7	13	20	33	44	66
16 to <18 years	1,087	16	4	7	14	22	33	43	58
18 to <21 years	1,245	17	2	6	13	23	36	44	82
≥21 years	8,673	22	6	11	19	29	41	50	70
≥65 years	2,287	20	7	11	18	26	36	45	61
All ages	18,216	22	5	11	18	29	43	53	84

[a] Includes all participants whether or not they ingested any water from the source during survey period.

[b] Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages. Does not include indirect consumption of bottled water.

- = Zero.

* Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993).

Source: U.S. EPA analysis of NHANES 2003–2006 data.

Table 3-32. Per Capita[a] Estimates of Combined Direct and Indirect[b] Water Ingestion Based on NHANES 2003–2006, Mean Confidence Intervals and Bootstrap Intervals for 90th and 95th Percentiles: All Sources (mL/kg-day)

Age	Sample Size	Mean			90th percentile			95th percentile		
			90% CI			90% BI			90% BI	
		Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound
Birth to <1 month	88	65*	45*	84*	173*	128*	195*	195*	168*	216*
1 to <3 months	143	67*	55*	78*	180*	152*	193*	194*	164*	204*
3 to <6 months	244	74*	65*	82*	153*	140*	178*	179*	157*	195*
6 to <12 months	466	52	47	57	113*	105*	124*	137*	123*	145*
1 to <2 years	611	33	30	36	68*	62*	73*	80*	73*	96*
2 to <3 years	571	32	29	35	67*	59*	72*	78*	71*	91*
3 to <6 years	1,091	27	25	29	52	47	54	63	57	68
6 to <11 years	1,601	22	20	23	42	39	46	52	49	55
11 to <16 years	2,396	16	15	17	33	30	37	44	38	53
16 to <18 years	1,087	16	15	18	33	29	35	43	36	45
18 to <21 years	1,245	17	15	19	36	33	39	44	41	47
≥21 years	8,673	22	21	23	41	40	42	50	48	51
≥65 years	2,287	20	20	21	36	34	38	45	42	46
All ages	18,216	22	21	23	43	42	44	53	51	54

[a] Includes all participants whether or not they ingested any water from the source during survey period.
[b] Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages. Does not include indirect consumption of bottled water.
* Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993).
CI = Confidence Interval.
BI = Bootstrap Interval.

Source: U.S. EPA analysis of NHANES 2003–2006 data.

Table 3-33. Consumer-Only[a] Estimates of Combined Direct and Indirect[b] Water Ingestion Based on NHANES 2003–2006: Community Water (mL/day)

Age	Sample size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	51	409*	72*	172*	399*	492*	851*	852*	990*
1 to <3 months	85	531*	103*	341*	513*	745*	957*	1,019*	1,197*
3 to <6 months	192	520*	89*	312*	530*	739*	880*	929*	1,248*
6 to <12 months	416	356	43*	94	270	551	772*	948*	1,161*
1 to <2 years	534	277	36*	88	199	377	627*	781*	1,277*
2 to <3 years	508	321	43*	105	227	448	722*	911*	1,374*
3 to <6 years	985	382	53	137	316	515	778	999	1,592*
6 to <11 years	1,410	511	79	178	413	690	1,072	1,404	2,099*
11 to <16 years	2,113	637	77	192	436	808	1,535	1,976	3,147
16 to <18 years	944	702	97	236	515	966	1,571	1,883	3,467
18 to <21 years	1,086	816	88	216	503	1,065	1,921	2,818	4,106
≥21 years	7,616	1,227	192	469	991	1,741	2,546	3,092	4,576
≥65 years	1,974	1,288	325	628	1,137	1,760	2,395	2,960	4,137
All ages	15,940	1,033	124	333	743	1,474	2,318	2,881	4,312

[a] Excludes individuals who did not ingest water from the source during the survey period.

[b] Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages.

* Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993).

Source: U.S. EPA analysis of NHANES 2003–2006 data.

Table 3-34. Consumer-Only[a] Estimates of Combined Direct and Indirect[b] Water Ingestion Based on NHANES 2003–2006: Bottled Water (mL/day)

Age	Sample size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	11	55*	15*	20*	27*	46*	59*	190*	275*
1 to <3 months	28	135*	13*	31*	58*	145*	309*	347*	377*
3 to <6 months	65	69*	10*	15*	35*	84*	156*	202*	479*
6 to <12 months	190	111*	13*	30*	58*	147*	261*	359*	627*
1 to <2 years	247	193*	43*	73*	126*	277*	385*	474*	682*
2 to <3 years	220	276*	38*	74*	155*	333*	681*	1,000*	1,315*
3 to <6 years	430	297	72	118	207	389	615	825*	1,305*
6 to <11 years	661	350	81	118	236	445	740	898*	1,934*
11 to <16 years	1,171	477	116	215	333	595	1,000	1,297	1,990
16 to <18 years	549	726	151	252	467	893	1,609	2,121	3,096*
18 to <21 years	662	783	178	255	497	1,019	1,698	2,324	3,824
≥21 years	3,836	840	162	281	637	1,137	1,777	2,363	3,665
≥65 years	7,442	749	100	178	409	824	1,346	1,940	2,717
All ages	8,070	738	118	237	500	999	1,640	2,133	3,601

[a] Excludes individuals who did not ingest water from the source during the survey period.

[b] Direct water is defined as water ingested directly as a beverage; indirect water, defined as water added in the preparation of food or beverages, was not accounted for in the estimation of bottled water intake.

* Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993) .

Source: U.S. EPA analysis of NHANES 2003–2006 data.

Table 3-35. Consumer-Only[a] Estimates of Combined Direct and Indirect[b] Water Ingestion Based on NHANES 2003–2006: Other Sources (mL/day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	41	121*	25*	59*	112*	166*	234*	246*	269*
1 to <3 months	67	187*	33*	120*	177*	236*	278*	400*	612*
3 to <6 months	160	237*	42*	130*	194*	265*	325*	730*	1,184*
6 to <12 months	287	223*	15*	46*	139*	235*	736*	877*	1,203*
1 to <2 years	312	155	9*	20	47	196	474*	628*	1,047*
2 to <3 years	256	163*	9*	19*	50*	214*	482*	798*	1,070*
3 to <6 years	449	155	9	22	57	178	485	631*	999*
6 to <11 years	609	270	16	40	124	386	814	1,065*	1,183*
11 to <16 years	1,116	367	15	44	131	451	1,044	1,467	2,376
16 to <18 years	467	457	12	49	133	530	1,368	2,159	3,122*
18 to <21 years	572	417	17	50	106	432	1,505	2,131	2,831*
≥21 years	3,555	672	32	80	216	926	1,980	2,774	4,285
≥65 years	834	816	64	143	546	1,319	1,923	2,309	3,283*
All ages	7,891	559	22	62	179	689	1,731	2,381	3,798

[a] Excludes individuals who did not ingest water from the source during the survey period.

[b] Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages. Does not include indirect consumption of bottled water.

* Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993) .

Source: U.S. EPA analysis of NHANES 2003–2006 data.

Table 3-36. Consumer-Only[a] Estimates of Combined Direct and Indirect[b] Water Ingestion Based on NHANES 2003–2006: All Sources (mL/day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	54	481*	74*	217*	473*	658*	921*	996*	1,165*
1 to <3 months	92	665*	103*	457*	704*	1,014*	1,076*	1,099*	1,328*
3 to <6 months	209	660*	55*	379*	685*	965*	1,101*	1,215*	1,450*
6 to <12 months	453	477	64*	152	393	765	1,021*	1,128*	1,526*
1 to <2 years	596	378	78*	173	300	497	772*	914*	1,421*
2 to <3 years	560	441	95*	203	341	589	920*	1,087*	1,450*
3 to <6 years	1,077	506	130	259	437	665	933	1,182	1,787*
6 to <11 years	1,580	666	155	348	574	875	1,186	1,585	2,305*
11 to <16 years	2,362	898	217	385	689	1,149	1,829	2,600	3,499
16 to <18 years	1,059	1,138	259	499	973	1,519	2,298	2,672	3,788
18 to <21 years	1,210	1,277	250	528	986	1,754	2,617	3,358	4,964
≥21 years	8,608	1,712	509	934	1,516	2,258	3,091	3,733	5,253
≥65 years	2,281	1,503	573	898	1,361	1,925	2,585	3,066	4,126
All ages	17,860	1,444	304	623	1,218	1,981	2,842	3,422	4,960

[a] Excludes individuals who did not ingest water from the source during the survey period.

[b] Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages. Does not include indirect consumption of bottled water.

* Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993) .

Source: U.S. EPA analysis of NHANES 2003–2006 data.

Table 3-37. Consumer-Only[a] Estimates of Combined Direct and Indirect[b] Water Ingestion Based on NHANES 2003–2006, Mean Confidence Intervals and Bootstrap Intervals for 90th and 95th Percentiles: All Sources (mL/day)

Age	Sample Size	Mean			90th percentile			95th percentile		
			90% CI			90% BI			90% BI	
		Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound
Birth to <1 month	54	481*	396*	566*	921*	715*	993*	996*	853*	1,041*
1 to <3 months	92	665*	626*	704*	1,076*	1,030*	1,097*	1,099*	1,073*	1,215*
3 to <6 months	209	660*	596*	724*	1,101*	1,032*	1,189*	1,215*	1,137*	1,256*
6 to <12 months	453	477	432	523	1,021*	906*	1,057*	1,128*	1,057*	1,238*
1 to <2 years	596	378	347	409	772*	674*	838*	914*	837*	1,086*
2 to <3 years	560	441	403	479	920*	837*	994*	1,087*	970*	1,242*
3 to <6 years	1,077	506	479	534	933	898	1,017	1,182	1,078	1,253
6 to <11 years	1,580	666	624	708	1,186	1,114	1,300	1,585	1,414	1,812
11 to <16 years	2,362	898	832	963	1,829	1,700	2,169	2,600	2,322	2,805
16 to <18 years	1,059	1,138	1,052	1,224	2,298	2,052	2,421	2,672	2,514	2,888
18 to <21 years	1,210	1,277	1,164	1,389	2,617	2,389	3,030	3,358	3,059	3,790
≥21 years	8,608	1,712	1,654	1,771	3,091	3,034	3,149	3,733	3,585	3,861
≥65 years	2,281	1,503	1,446	1,560	2,585	2,471	2,688	3,066	2,961	3,316
All ages	17,860	1,444	1,395	1,492	2,842	2,796	2,917	3,422	3,363	3,510

[a] Excludes individuals who did not ingest water from the source during the survey period.

[b] Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages. Does not include indirect consumption of bottled water.

* Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993).

CI = Confidence Interval.

BI = Bootstrap Interval.

Source: U.S. EPA analysis of NHANES 2003–2006 data.

Table 3-38. Consumer-Only[a] Estimates of Direct and Indirect[b] Water Ingestion Based on NHANES 2003–2006: Community Water (mL/kg-day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	51	90*	13*	40*	89*	120*	167*	172*	228*
1 to <3 months	85	93*	17*	62*	91*	118*	163*	186*	210*
3 to <6 months	192	73*	10*	45*	74*	100*	128*	140*	191*
6 to <12 months	416	40	5*	10	30	64	87*	104*	135*
1 to <2 years	534	25	3*	8	17	31	56*	71*	117*
2 to <3 years	508	23	3*	8	16	33	52*	62*	108*
3 to <6 years	985	21	3	8	17	29	43	52	83*
6 to <11 years	1,410	17	2	6	13	23	35	47	78*
11 to <16 years	2,113	12	1	4	8	15	26	35	62
16 to <18 years	944	10	1	4	8	15	23	30	47
18 to <21 years	1,086	11	1	3	7	15	26	36	58
≥21 years	7,616	16	2	6	12	22	34	42	64
≥65 years	1,974	18	4	8	15	23	34	43	60
All ages	15,940	16	2	6	12	22	35	44	76

[a] Excludes individuals who did not ingest water from the source during the survey period.
[b] Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages.
* Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993).

Source: U.S. EPA analysis of NHANES 2003–2006 data.

Table 3-39. Consumer-Only[a] Estimates of Direct[b] Water Ingestion Based on NHANES 2003–2006: Bottled Water (mL/kg-day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	11	12*	3*	6*	7*	8*	17*	38*	58*
1 to <3 months	28	24*	2*	6*	9*	23*	55*	63*	68*
3 to <6 months	65	10*	2*	2*	5*	11*	21*	27*	81*
6 to <12 months	190	12*	2*	4*	7*	16*	29*	36*	63*
1 to <2 years	247	17*	4*	7*	13*	23*	35*	44*	62*
2 to <3 years	220	20*	3*	5*	11*	23*	48*	68*	111*
3 to <6 years	430	16	4	7	11	20	34	47*	67*
6 to <11 years	661	11	2	4	7	13	26	31*	60*
11 to <16 years	1,171	9	2	4	6	11	19	23	35
16 to <18 years	549	11	2	4	7	14	24	34	58*
18 to <21 years	662	11	3	4	7	14	24	33	52
≥21 years	3,836	11	2	3	8	14	23	29	51
≥65 years	7,442	11	1	2	6	11	18	28	41
All ages	8,070	11	2	4	8	14	24	31	54

a Excludes individuals who did not ingest water from the source during the survey period.
b Direct water is defined as water ingested directly as a beverage; indirect water, defined as water added in the preparation of food or beverages, was not accounted for in the estimation of bottled water intake.
* Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993).

Source: U.S. EPA analysis of NHANES 2003–2006 data.

Table 3-40. Consumer-Only[a] Estimates of Direct and Indirect[b] Water Ingestion Based on NHANES 2003–2006: Other Sources (mL/kg-day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	41	26*	4*	13*	26*	33*	47*	51*	55*
1 to <3 months	67	31*	5*	22*	32*	37*	49*	69*	87*
3 to <6 months	160	33*	5*	17*	27*	36*	51*	113*	179*
6 to <12 months	287	25*	2*	5*	16*	28*	69*	98*	142*
1 to <2 years	312	14	1*	2	4	17	43*	54*	97*
2 to <3 years	256	12*	1*	1*	4*	15*	35*	62*	75*
3 to <6 years	449	8	0	1	3	11	24	28*	54*
6 to <11 years	609	9	1	1	4	13	23	33*	45*
11 to <16 years	1,116	6	0	1	2	8	18	23	41
16 to <18 years	467	6	0	1	2	6	21	27	42*
18 to <21 years	572	6	0	1	2	5	20	28	42*
≥21 years	3,555	9	0	1	3	11	25	35	53
≥65 years	834	11	1	2	7	18	25	33	42*
All ages	7,891	9	0	1	3	11	25	35	55

[a] Excludes individuals who did not ingest water from the source during the survey period.
[b] Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages. Does not include indirect consumption of bottled water.
* Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993).

Source: U.S. EPA analysis of NHANES 2003–2006 data.

Table 3-41. Consumer-Only[a] Estimates of Direct and Indirect[b] Water Ingestion Based on NHANES 2003–2006: All Sources (mL/kg-day)

Age	Sample Size	Mean	Percentile						
			10	25	50	75	90	95	99
Birth to <1 month	54	105*	15*	46*	120*	141*	189*	211*	255*
1 to <3 months	92	115*	18*	71*	119*	160*	193*	201*	241*
3 to <6 months	209	92*	8*	50*	95*	132*	163*	186*	238*
6 to <12 months	453	54	7*	16	44	84	114*	137*	183*
1 to <2 years	596	34	7*	15	26	44	68*	82*	122*
2 to <3 years	560	32	7*	15	25	43	67*	78*	123*
3 to <6 years	1,077	27	7	14	24	37	52	63	96*
6 to <11 years	1,580	22	5	11	18	28	42	52	78*
11 to <16 years	2,362	16	4	7	13	20	33	44	66
16 to <18 years	1,059	17	4	7	14	22	33	44	59
18 to <21 years	1,210	18	3	7	14	23	36	45	83
≥21 years	8,608	22	6	12	19	29	41	50	70
≥65 years	2,281	20	7	12	18	26	36	45	61
All ages	17,860	22	6	11	19	29	43	53	84

[a] Excludes individuals who did not ingest water from the source during the survey period.

[b] Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages. Does not include indirect consumption of bottled water.

* Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993).

Source: U.S. EPA analysis of NHANES 2003–2006 data.

Table 3-42. Consumer-Only[a] Estimates of Direct and Indirect[b] Water Ingestion Based on NHANES 2003–2006, Mean Confidence Intervals and Bootstrap Intervals for 90th and 95th Percentiles: All Sources (mL/kg-day)

Age	Sample Size	Mean			90th percentile			95th percentile		
			90% CI			90% BI			90% BI	
		Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound
Birth to <1 month	54	105*	86*	125*	189*	160*	211*	211*	174*	238*
1 to <3 months	92	115*	106*	125*	193*	164*	199*	201*	188*	222*
3 to <6 months	209	92*	84*	101*	163*	143*	179*	186*	171*	201*
6 to <12 months	453	54	49	59	114*	105*	126*	137*	124*	146*
1 to <2 years	596	34	31	37	68*	62*	74*	82*	74*	100*
2 to <3 years	560	32	29	35	67*	60*	72*	78*	72*	92*
3 to <6 years	1,077	27	26	29	52	48	54	63	57	70
6 to <11 years	1,580	22	21	24	42	39	46	52	49	55
11 to <16 years	2,362	16	15	18	33	30	37	44	39	53
16 to <18 years	1,059	17	16	18	33	29	35	44	36	45
18 to <21 years	1,210	18	16	19	36	33	39	45	42	48
≥21 years	8,608	22	21	23	41	40	43	50	48	51
≥65 years	2,281	20	20	21	36	34	39	45	42	47
All ages	17,860	22	22	23	43	42	44	53	52	54

[a] Excludes individuals who did not ingest water from the source during the survey period.
[b] Direct water is defined as water ingested directly as a beverage; indirect water is defined as water added in the preparation of food or beverages. Does not include indirect consumption of bottled water.
* Estimates are less statistically reliable based on guidance published in the *Joint Policy on Variance Estimation and Statistical Reporting Standards on NHANES III and CSFII Reports: NHIS/NCHS Analytical Working Group Recommendations* (NCHS, 1993).
CI = Confidence Interval.
BI = Bootstrap Interval.

Source: U.S. EPA analysis of NHANES 2003–2006 data.

Table 3-43. Assumed Tap Water Content of Beverages in Great Britain

Beverage	% Tap Water
Cold Water	100
Home-made Beer/Cider/Lager	100
Home-made Wine	100
Other Hot Water Drinks	100
Ground/Instant Coffee:[a]	
Black	100
White	80
Half Milk	50
All Milk	0
Tea	80
Hot Milk	0
Cocoa/Other Hot Milk Drinks	0
Water-based Fruit Drink	75
Fizzy Drinks	0
Fruit Juice Type 1[b]	0
Fruit Juice Type 2[b]	75
Milk	0
Mineral Water[c]	0
Bought cider/beer/lager	0
Bought Wine	0

[a] Black—coffee with all water, milk not added; White—coffee with 80% water, 20% milk; Half Milk—coffee with 50% water, 50% milk; All Milk—coffee with all milk, water not added.

[b] Fruit juice: individuals were asked in the questionnaire if they consumed ready-made fruit juice (Type 1 above), or the variety that is diluted (Type 2).

[c] Information on volume of mineral water consumed was obtained only as "number of bottles per week." A bottle was estimated at 500 mL, and the volume was split so that 2/7 was assumed to be consumed on weekends, and 5/7 during the week.

Source: Hopkins and Ellis (1980).

Table 3-44. Intake of Total Liquid, Total Tap Water, and Various Beverages (L/day) by the British Population

Beverage	All Individuals					Consumers Only[a]			
	Mean Intake	Approx. Std. Error of Mean	Approx. 95% Confidence Interval for Mean	10 and 90 Percentiles	1 and 99 Percentiles	Percentage of Total Number of Individuals	Mean Intake	Approx. Std. Error of Mean	Approx. 95% Confidence Interval for Mean
Total Liquid	1.589	0.0203	1.547–1.629	0.77–2.57	0.34–4.50	100	1.589	0.0203	1.547–1.629
Total Liquid Home	1.104	0.0143	1.075–1.133	0.49–1.79	0.23–3.10	100	1.104	0.0143	1.075–1.133
Total Liquid Away	0.484	0.0152	0.454–0.514	0.00–1.15	0.00–2.89	89.9	0.539	0.0163	0.506–0.572
Total Tap Water	0.955	0.0129	0.929–0.981	0.39–1.57	0.10–2.60	99.8	0.958	0.0129	0.932–0.984
Total Tap Water Home	0.754	0.0116	0.731–0.777	0.26–1.31	0.02–2.30	99.4	0.759	0.0116	0.736–0.782
Total Tap Water Away	0.201	0.0056	0.190–0.212	0.00–0.49	0.00–0.96	79.6	0.253	0.0063	0.240–0.266
Tea	0.584	0.0122	0.560–0.608	0.01–1.19	0.00–2.03	90.9	0.643	0.0125	0.618–0.668
Coffee	0.19	0.0059	0.178–0.202	0.00–0.56	0.00–1.27	63	0.302	0.0105	0.281–0.323
Other Hot Water Drinks	0.011	0.0015	0.008–0.014	0.00–0.00	0.00–0.25	9.2	0.12	0.0133	0.093–0.147
Cold Water	0.103	0.0049	0.093–0.113	0.00–0.31	0.00–0.85	51	0.203	0.0083	0.186–0.220
Fruit Drinks	0.057	0.0027	0.052–0.062	0.00–0.19	0.00–0.49	46.2	0.123	0.0049	0.113–0.133
Non-Tap Water	0.427	0.0058	0.415–0.439	0.20–0.70	0.06–1.27	99.8	0.428	0.0058	0.416–0.440
Home-brew	0.01	0.0017	0.007–0.013	0.00–0.00	0.00–0.20	7	0.138	0.0209	0.096–0.180
Bought Alcoholic Beverages	0.206	0.0123	0.181–0.231	0.00–0.68	0.00–2.33	43.5	0.474	0.025	0.424–0.524

[a] “Consumers only” is defined as only those individuals who reported consuming the beverage during the survey period.

Source: Hopkins and Ellis (1980).

Table 3-45. Summary of Total Liquid and Total Tap Water Intake for Males and Females (L/day) in Great Britain

Beverage	Age Group (years)	Number		Mean Intake		Approx. Std. Error of Mean		Approx 95% Confidence Interval for Mean		10 and 90 Percentiles	
		Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
Total Liquid Intake	1 to 4	88	75	0.853	0.888	0.0557	0.066	0.742–0.964	0.756–1.020	0.38–1.51	0.39–1.48
	5 to 11	249	201	0.986	0.902	0.0296	0.0306	0.917–1.045	0.841–0.963	0.54–1.48	0.51–1.39
	12 to 17	180	169	1.401	1.198	0.0619	0.0429	1.277–1.525	1.112–1.284	0.75–2.27	0.65–1.74
	18 to 30	333	350	2.184	1.547	0.0691	0.0392	2.046–2.322	1.469–1.625	1.12–3.49	0.93–2.30
	31 to 54	512	551	2.112	1.601	0.0526	0.0215	2.007–2.217	1.558–1.694	1.15–3.27	0.95–2.36
	≥55	396	454	1.83	1.482	0.0498	0.0356	1.730–1.930	1.411–1.553	1.03–2.77	0.84–2.17
Total Tap Water Intake	1 to 4	88	75	0.477	0.464	0.0403	0.0453	0.396–0.558	0.373–0.555	0.17–0.85	0.15–0.89
	5 to 11	249	201	0.55	0.533	0.0223	0.0239	0.505–0.595	0.485–0.581	0.22–0.90	0.22–0.93
	12 to 17	180	169	0.805	0.725	0.0372	0.0328	0.731–0.8790	0.659–0.791	0.29–1.35	0.31–1.16
	18 to 30	333	350	1.006	0.991	0.0363	0.0304	0.933–1.079	0.930–1.052	0.45–1.62	0.50–1.55
	31 to 54	512	551	1.201	1.091	0.0309	0.024	1.139–1.263	1.043–1.139	0.64–1.88	0.62–1.68
	≥55	396	454	1.133	1.027	0.0347	0.0273	1.064–1.202	0.972–1.082	0.62–1.72	0.54–1.57

Source: Hopkins and Ellis (1980).

Table 3-46. Daily Total Tap Water Intake Distribution for Canadians, by Age Group (approx. 0.20-L increments, both sexes, combined seasons)

Amount Consumed[a] L/day	Age Group (years)					
	5 and Under		6 to 17		18 and Over	
	%	Number	%	Number	%	Number
0.00–0.21	11.1	9	2.8	7	0.5	3
0.22–0.43	17.3	14	10.0	25	1.9	12
0.44–0.65	24.8	20	13.2	33	5.9	38
0.66–0.86	9.9	8	13.6	34	8.5	54
0.87–1.07	11.1	9	14.4	36	13.1	84
1.08–1.29	11.1	9	14.8	37	14.8	94
1.30–1.50	4.9	4	9.6	24	15.3	98
1.51–1.71	6.2	5	6.8	17	12.1	77
1.72–1.93	1.2	1	2.4	6	6.9	44
1.94–2.14	1.2	1	1.2	3	5.6	36
2.15–2.36	1.2	1	4.0	10	3.4	22
2.37–2.57	-	0	0.4	1	3.1	20
2.58–2.79	-	0	2.4	6	2.7	17
2.80–3.00	-	0	2.4	6	1.4	9
3.01–3.21	-	0	0.4	1	1.1	7
3.22–3.43	-	0	-	0	0.9	6
3.44–3.64	-	0	-	0	0.8	5
3.65–3.86	-	0	-	0	-	0
>3.86	-	0	1.6	4	2.0	13
TOTAL	100.0	81	100.0	250	100.0	639

[a] Includes tap water and foods and beverages derived from tap water.

Source: Canadian Ministry of National Health and Welfare (1981).

Table 3-47. Average Daily Tap Water Intake of Canadians (expressed as mL/kg body weight)

Age Group (years)	Average Daily Intake (mL/kg)		
	Females	Males	Both Sexes
<3	53	35	45
3 to 5	49	48	48
6 to 17	24	27	26
18 to 34	23	19	21
35 to 54	25	19	22
≥55	24	21	22
Total Population	24	21	22

Source: Canadian Ministry of National Health and Welfare (1981).

Table 3-48. Average Daily Total Tap Water Intake of Canadians, by Age and Season (L/day)[a]

	Age (years)						
	<3	3 to 5	6 to 17	18 to 34	35 to 54	≥55	All Ages
Average							
Summer	0.57	0.86	1.14	1.33	1.52	1.53	1.31
Winter	0.66	0.88	1.13	1.42	1.59	1.62	1.37
Summer/Winter	0.61	0.87	1.14	1.38	1.55	1.57	1.34
90th Percentile							
Summer/Winter	1.5	1.5	2.21	2.57	2.57	2.29	2.36

[a] Includes tap water and foods and beverages derived from tap water.

Source: Canadian Ministry of National Health and Welfare (1981).

Table 3-49. Average Daily Total Tap Water Intake of Canadians as a Function of Level of Physical Activity at Work and in Spare Time (16 years and older, combined seasons, L/day)

	Work		Spare Time	
Activity Level[a]	Consumption[b] L/day	Number of Respondents	Consumption[b] L/day	Number of Respondents
Extremely Active	1.72	99	1.57	52
Very Active	1.47	244	1.51	151
Somewhat Active	1.47	217	1.44	302
Not Very Active	1.27	67	1.52	131
Not At All Active	1.3	16	1.35	26
Did Not State	1.3	45	1.31	26
TOTAL		688		688

[a] The levels of physical activity listed here were not defined any further by the survey report, and categorization of activity level by survey participants is assumed to be subjective.
[b] Includes tap water and foods and beverages derived from tap water.

Source: Canadian Ministry of National Health and Welfare (1981).

Table 3-50. Average Daily Tap Water Intake by Canadians, Apportioned Among Various Beverages (both sexes, by age, combined seasons, L/day)[a]

	Age Group (years)					
	<3	3 to 5	6 to 17	18 to 34	35 to 54	≥55
Total Number in Group	34	47	250	232	254	153
Water	0.14	0.31	0.42	0.39	0.38	0.38
Ice/Mix	0.01	0.01	0.02	0.04	0.03	0.02
Tea	*	0.01	0.05	0.21	0.31	0.42
Coffee	0.01	*	0.06	0.37	0.5	0.42
"Other Type of Drink"	0.21	0.34	0.34	0.2	0.14	0.11
Reconstituted Milk	0.1	0.08	0.12	0.05	0.04	0.08
Soup	0.04	0.08	0.07	0.06	0.08	0.11
Homemade Beer/Wine	*	*	0.02	0.04	0.07	0.03
Homemade Popsicles	0.01	0.03	0.03	0.01	*	*
Baby Formula, etc.	0.09	*	*	*	*	*
TOTAL	0.61	0.86	1.14	1.38	1.55	1.57

[a] Includes tap water and foods and beverages derived from tap water.
* Less than 0.01 L/day.

Source: Canadian Ministry of National Health and Welfare (1981).

Table 3-51. Intake Rates of Total Fluids and Total Tap Water by Age Group

Age Group	Average Daily Consumption Rate (L/day) Total Fluids[a]	Total Tap Water[b]
6 to 11 months	0.80	0.20
2 years	0.99	0.50
14 to 16 years	1.47	0.72
25 to 30 years	1.76	1.04
60 to 65 years	1.63	1.26

[a] Includes milk, "ready-to-use" formula, milk-based soup, carbonated soda, alcoholic beverages, canned juices, water, coffee, tea, reconstituted juices, and reconstituted soups. Does not include reconstituted infant formula.

[b] Includes water, coffee, tea, reconstituted juices, and reconstituted soups.

Source: Derived from Pennington (1983)

Table 3-52. Mean and Standard Error for the Daily Intake of Beverages and Tap Water by Age

Age (years)	Tap Water Intake (mL)	Water-Based Drinks (mL)[a]	Soups (mL)	Total Beverage Intake[b] (mL)
All ages	662.5 ± 9.9	457.1 ± 6.7	45.9 ± 1.2	1,434.0 ± 13.7
<1	170.7 ± 64.5	8.3 ± 43.7	10.1 ± 7.9	307.0 ± 89.2
1 to 4	434.6 ± 31.4	97.9 ± 21.5	43.8 ± 3.9	743.0 ± 43.5
5 to 9	521.0 ± 26.4	116.5 ± 18.0	36.6 ± 3.2	861.0 ± 36.5
10 to 14	620.2 ± 24.7	140.0 ± 16.9	35.4 ± 3.0	1,025.0 ± 34.2
15 to 19	664.7 ± 26.0	201.5 ± 17.7	34.8 ± 3.2	1,241.0 ± 35.9
20 to 24	656.4 ± 33.9	343.1 ± 23.1	38.9 ± 4.2	1,484.0 ± 46.9
25 to 29	619.8 ± 34.6	441.6 ± 23.6	41.3 ± 4.2	1,531.0 ± 48.0
30 to 39	636.5 ± 27.2	601.0 ± 18.6	40.6 ± 3.3	1,642.0 ± 37.7
40 to 59	735.3 ± 21.1	686.5 ± 14.4	51.6 ± 2.6	1,732.0 ± 29.3
≥60	762.5 ± 23.7	561.1 ± 16.2	59.4 ± 2.9	1,547.0 ± 32.8

[a] Includes water-based drinks such as coffee, etc. Reconstituted infant formula does not appear to be included in this group.

[b] Includes tap water and water-based drinks such as coffee, tea, soups, and other drinks such as soft drinks, fruitades, and alcoholic drinks.

Source: U.S. EPA (1984).

Table 3-53. Average Total Tap Water Intake Rate by Sex, Age, and Geographic Area

Group/Subgroup	Number of Respondents	Average Total Tap Water Intake,[a,b] L/day
Total group	5,258	1.39
Sex		
Males	3,892	1.40
Females	1,366	1.35
Age, years		
21 to 44	291	1.30
45 to 64	1,991	1.48
65 to 84	2,976	1.33
Geographic area		
Atlanta	207	1.39
Connecticut	844	1.37
Detroit	429	1.33
Iowa	743	1.61
New Jersey	1,542	1.27
New Mexico	165	1.49
New Orleans	112	1.61
San Francisco	621	1.36
Seattle	316	1.44
Utah	279	1.35

[a] Standard deviations not reported in Cantor et al. (1987).
[b] Total tap water defined as all water and beverages derived from tap water.

Source: Cantor et al. (1987).

Table 3-54. Frequency Distribution of Total Tap Water Intake Rates[a]

Consumption Rate (L/day)	Frequency[b] (%)	Cumulative Frequency[b] (%)
≤0.80	20.6	20.6
0.81–1.12	21.3	41.9
1.13–1.44	20.5	62.4
1.45–1.95	19.5	81.9
≥1.96	18.1	100.0

[a] Represents consumption of tap water and beverages derived from tap water in a "typical" winter week.
[b] Extracted from Table 3 in the article by Cantor et al. (1987).

Source: Cantor et al. (1987).

Table 3-55. Total Tap Water Intake (mL/day) for Both Sexes Combined[a]

Age (years)	Number of Observations	Mean	SD	SE of Mean	Percentile Distribution								
					1	5	10	25	50	75	90	95	99
<0.5	182	272	247	18	*	0	0	80	240	332	640	800	*
0.5 to 0.9	221	328	265	18	*	0	0	117	268	480	688	764	*
1 to 3	1,498	646	390	10	33	169	240	374	567	820	1,162	1,419	1,899
4 to 6	1,702	742	406	10	68	204	303	459	660	972	1,302	1,520	1,932
7 to 10	2,405	787	417	9	68	241	318	484	731	1,016	1,338	1,556	1,998
11 to 14	2,803	925	521	10	76	244	360	561	838	1,196	1,621	1,924	2,503
15 to 19	2,998	999	593	11	55	239	348	587	897	1,294	1,763	2,134	2,871
20 to 44	7,171	1,255	709	8	105	337	483	766	1,144	1,610	2,121	2,559	3,634
45 to 64	4,560	1,546	723	11	335	591	745	1,057	1,439	1,898	2,451	2,870	3,994
65 to 74	1,663	1,500	660	16	301	611	766	1,044	1,394	1,873	2,333	2,693	3,479
≥75	878	1,381	600	20	279	568	728	961	1,302	1,706	2,170	2,476	3,087
Infants (ages <1)	403	302	258	13	0	0	0	113	240	424	649	775	1,102
Children (ages 1 to 10)	5,605	736	410	5	56	192	286	442	665	960	1,294	1,516	1,954
Teens (ages 11 to 19)	5,801	965	562	7	67	240	353	574	867	1,246	1,701	2,026	2,748
Adults (ages 20 to 64)	11,731	1,366	728	7	148	416	559	870	1,252	1,737	2,268	2,707	3,780
Adults (ages ≥65)	2,541	1,459	643	13	299	598	751	1,019	1,367	1,806	2,287	2,636	3,338
All	26,081	1,193	702	4	80	286	423	690	1,081	1,561	2,092	2,477	3,415

[a] Total tap water is defined as "all water from the household tap consumed directly as a beverage or used to prepare foods and beverages."
* Value not reported due to insufficient number of observations.
SD = Standard deviation.
SE = Standard error.

Source: Ershow and Cantor (1989).

Table 3-56. Total Tap Water Intake (mL/kg-day) for Both Sexes Combined[a]

Age (years)	Number of Observations: Actual Count	Number of Observations: Weighted Count	Mean	SD	SE of Mean	Percentile Distribution: 1	5	10	25	50	75	90	95	99
<0.5	182	201.2	52.4	53.2	3.9	*	0	0	14.8	37.8	66.1	128.3	155.6	*
0.5 to 0.9	221	243.2	36.2	29.2	2	*	0	0	15.3	32.2	48.1	69.4	102.9	*
1 to 3	1,498	1,687.7	46.8	28.1	0.7	2.7	11.8	17.8	27.2	41.4	60.4	82.1	101.6	140.6
4 to 6	1,702	1,923.9	37.9	21.8	0.5	3.4	10.3	14.9	21.9	33.3	48.7	69.3	81.1	103.4
7 to 10	2,405	2,742.4	26.9	15.3	0.3	2.2	7.4	10.3	16	24	35.5	47.3	55.2	70.5
11 to 14	2,803	3,146.9	20.2	11.6	0.2	1.5	4.9	7.5	11.9	18.1	26.2	35.7	41.9	55
15 to 19	2,998	3,677.9	16.4	9.6	0.2	1	3.9	5.7	9.6	14.8	21.5	29	35	46.3
20 to 44	7,171	13,444.5	18.6	10.7	0.1	1.6	4.9	7.1	11.2	16.8	23.7	32.2	38.4	53.4
45 to 64	4,560	8,300.4	22	10.8	0.2	4.4	8	10.3	14.7	20.2	27.2	35.5	42.1	57.8
65 to 74	1,663	2,740.2	21.9	9.9	0.2	4.6	8.7	10.9	15.1	20.2	27.2	35.2	40.6	51.6
≥75	878	1,401.8	21.6	9.5	0.3	3.8	8.8	10.7	15	20.5	27.1	33.9	38.6	47.2
Infants (ages <1)	403	444.3	43.5	42.5	2.1	0	0	0	15.3	35.3	54.7	101.8	126.5	220.5
Children (ages 1 to 10)	5,605	6,354.1	35.5	22.9	0.3	2.7	8.3	12.5	19.6	30.5	46.0	64.4	79.4	113.9
Teens (ages 11 to 19)	5,801	6,824.9	18.2	10.8	0.1	1.2	4.3	6.5	10.6	16.3	23.6	32.3	38.9	52.6
Adults (ages 20 to 64)	11,731	21,744.9	19.9	10.8	0.1	2.2	5.9	8.0	12.4	18.2	25.3	33.7	40.0	54.8
Adults (ages ≥65)	2,541	4,142.0	21.8	9.8	0.2	4.5	8.7	10.9	15.0	20.3	27.1	34.7	40.0	51.3
All	26,081	39,510.2	22.6	15.4	0.1	1.7	5.8	8.2	13.0	19.4	28.0	39.8	50.0	79.8

[a] Total tap water is defined as "all water from the household tap consumed directly as a beverage or used to prepare foods and beverages."
* Value not reported due to insufficient number of observations.
SD = Standard deviation.
SE = Standard error.

Source: Ershow and Cantor (1989).

Table 3-57. Summary of Tap Water Intake by Age

Age Group	Intake (mL/day)		Intake (mL/kg-day)	
	Mean	10th–90th Percentiles	Mean	10th–90th Percentiles
Infants (<1 year)	302	0–649	43.5	0–100
Children (1 to 10 years)	736	286–1,294	35.5	12.5–64.4
Teens (11 to 19 years)	965	353–1,701	18.2	6.5–32.3
Adults (20 to 64 years)	1,366	559–2,268	19.9	8.0–33.7
Adults (≥65 years)	1,459	751–2,287	21.8	10.9–34.7
All ages	1,193	423–2,092	22.6	8.2–39.8

Source: Ershow and Cantor (1989).

Table 3-58. Total Tap Water Intake (as % of total water intake) by Broad Age Category[a,b]

Age (years)	Mean	Percentile Distribution								
		1	5	10	25	50	75	90	95	99
<1	26	0	0	0	12	22	37	55	62	82
1 to 10	45	6	19	24	34	45	57	67	72	81
11 to 19	47	6	18	24	35	47	59	69	74	83
20 to 64	59	12	27	35	49	61	72	79	83	90
≥65	65	25	41	47	58	67	74	81	84	90

a Does not include pregnant women, lactating women, or breast-fed children.
b Total tap water is defined as "all water from the household tap consumed directly as a beverage or used to prepare foods and beverages."
0 = Less than 0.5%.

Source: Ershow and Cantor (1989).

Table 3-59. General Dietary Sources of Tap Water for Both Sexes[a,b]

Age (years)	Source	% of Tap Water Mean	Standard Deviation	5	25	50	75	95	99
<1	Food[c]	11	24	0	0	0	10	70	100
	Drinking Water	69	37	0	39	87	100	100	100
	Other Beverages	20	33	0	0	0	22	100	100
	All Sources	100							
1 to 10	Food[c]	15	16	0	5	10	19	44	100
	Drinking Water	65	25	0	52	70	84	96	100
	Other Beverages	20	21	0	0	15	32	63	93
	All Sources	100							
11 to 19	Food[c]	13	15	0	3	8	17	38	100
	Drinking Water	65	25	0	52	70	85	98	100
	Other Beverages	22	23	0	0	16	34	68	96
	All Sources	100							
20 to 64	Food[c]	8	10	0	2	5	11	25	49
	Drinking Water	47	26	0	29	48	67	91	100
	Other Beverages	45	26	0	25	44	63	91	100
	All Sources	100							
≥65	Food[c]	8	9	0	2	5	11	23	38
	Drinking Water	50	23	0	36	52	66	87	99
	Other Beverages	42	23	3	27	40	57	85	100
	All Sources	100							
All	Food[c]	10	13	0	2	6	13	31	64
	Drinking Water	54	27	0	36	56	75	95	100
	Other Beverages	36	27	0	14	34	55	87	100
	All Sources	100							

[a] Does not include pregnant women, lactating women, or breast-fed children.
[b] Individual values may not add to totals due to rounding.
[c] Food category includes soups.
0 = Less than 0.5%.

Source: Ershow and Cantor (1989).

Table 3-60. Summary Statistics for Best-Fit Lognormal Distributions for Water Intake Rates[a]

Group (Age in Years)	In Total Fluid Intake Rate		
	μ	σ	R^2
<1	6.979	0.291	0.996
1 to <11	7.182	0.340	0.953
11 to <20	7.490	0.347	0.966
20 to <65	7.563	0.400	0.977
≥ 65	7.583	0.360	0.988
All ages	7.487	0.405	0.984
Simulated balanced population	7.492	0.407	1.000
Group (Age in Years)	In Total Fluid Intake Rate		
	μ	σ	R^2
<1	5.587	0.615	0.970
1 to <11	6.429	0.498	0.984
11 to <20	6.667	0.535	0.986
20 to <65	7.023	0.489	0.956
≥ 65	7.088	0.476	0.978
All ages	6.870	0.530	0.978
Simulated balanced population	6.864	0.575	0.995

[a] These values (mL/day) were used in the following equations to estimate the quantiles and averages for total tap water intake shown in Table 3-61.
97.5 percentile intake rate = exp [μ + (1.96 × σ)]
75 percentile intake rate = exp [μ + (0.6745 × σ)]
50 percentile intake rate = exp [μ]
25 percentile intake rate = exp [μ – (0.6745 × σ)]
2.5 percentile intake rate = exp [μ – (1.96 × σ)]
Mean intake rate – exp [μ + 0.5 × σ^2)]

Source: Roseberry and Burmaster (1992).

Table 3-61. Estimated Quantiles and Means for Total Tap Water Intake Rates (mL/day)[a]

Age Group (years)	Percentile					Arithmetic Average
	2.5	25	50	75	97.5	
<1	80	176	267	404	891	323
1 to <11	233	443	620	867	1,644	701
11 to <20	275	548	786	1,128	2,243	907
20 to <65	430	807	1,122	1,561	2,926	1,265
≥ 65	471	869	1,198	1,651	3,044	1,341
All ages	341	674	963	1,377	2,721	1,108
Simulated Balanced Population	310	649	957	1,411	2,954	1,129

[a] Total tap water is defined as "all water from the household tap consumed directly as a beverage or used to prepare foods and beverages."

Source: Roseberry and Burmaster (1992).

Table 3-62 . Water Ingested (mL/day)[a] From Water by Itself and Water Added to Other Beverages and Foods

Category		6 Weeks (*N* = 124)	3 Months (*N* = 120)	6 Months (*N* = 99)	9 Months (*N* = 77)
Water by Itself	Range	0–355	0–355	0–266	0–473
	Per capita mean[b] ± SD	30 ± 89	30 ± 59	30 ± 59	89 ± 89
	Consumer-only mean[c]	89	89	118	118
	Percent consuming[d]	28	24	42	66
Water Added to Formula-Powdered Concentrate	Range	0–1,242	0–1,242	0–1,124	0–1,064
	Per capita mean ± SD	177 ± 296	266 ± 384	266 ± 355	207 ± 325
	Consumer-only mean	473	621	562	562
	Percent consuming	39	42	48	36
Liquid Concentrate	Range	0–621	0–680	0–710	0–532
	Per capita mean ± SD	89 ± 148	237 ± 207	148 ± 207	59 ± 148
	Consumer-only mean	355	384	414	325
	Percent consuming	23	30	35	21
All Concentrated Formula	Range	0–1,242	0–1,242	0–1,123	0–1,064
	Per capita mean ± SD	266 ± 296	384 ± 355	414 ± 325	266 ± 296
	Consumer-only mean	444	562	532	503
	Percent consuming	60	68	81	56
Water Added to Juices and Other Beverages	Range	0–118	0–710	0–473	0–887
	Per capita mean ± SD	<30 ± 30	30 ± 89	30 ± 89	59 ± 148
	Consumer-only mean	89	207	148	207
	Percent consuming	3	9	18	32
Water Added to Powdered Baby Foods and Cereals	Range	0–30	0–177	0–266	0–177
	Per capita mean ± SD	<30 ± 30	<30 ± 30	59 ± 59	30 ± 59
	Consumer-only mean	30	59	89	89
	Percent consuming	2	17	64	43
Water Added to Other Foods (Soups, Jell-o, Puddings)	Range	-	0–118	0–118	0–355
	Per capita mean ± SD	-	30 ± 30	<30 ± 30	30 ± 59
	Consumer-only mean	-	89	59	118
	Percent consuming	0	2	8	29
ALL SOURCES OF WATER	Range	0–1,242	0–1,419	0–1,123	0–1,745
	Per capita mean ± SD	296 ± 325	414 ± 414	473 ± 325	444 ± 355
	Consumer-only mean	414	562	503	473
	Percent consuming	68	77	94	97

[a] Converted from ounces/day; 1 fluid ounce = 29.57 mL.
[b] Mean intake among entire sample.
[c] Mean intake for only those ingesting water from the particular category.
[d] Percentage of infants receiving water from that individual source.
N = Number of observations.
SD = Standard deviation.
\- Indicates there is insufficient sample size to estimate means.

Source: Levy et al. (1995).

Table 3-63. Mean Per Capita Drinking Water Intake Based on USDA, CSFII Data From 1989–1991 (mL/day)

Sex and Age (years)	Plain Drinking Water	Coffee	Tea	Fruit Drinks and Ades[a]	Total
Males and Females:					
<1	194	0	<0.5	17	211.5
1 to 2	333	<0.5	9	85	427.5
3 to 5	409	2	26	100	537
≤5	359	1	17	86	463
Males:					
6 to 11	537	2	44	114	697
12 to 19	725	12	95	104	936
20 to 29	842	168	136	101	1,247
30 to 39	793	407	136	50	1,386
40 to 49	745	534	149	53	1,481
50 to 59	755	551	168	51	1,525
60 to 69	946	506	115	34	1,601
70 to 79	824	430	115	45	1,414
≥80	747	326	165	57	1,295
≥20	809	408	139	60	1,416
Females:					
6 to 11	476	1	40	86	603
12 to 19	604	21	87	87	799
20 to 29	739	154	120	61	1,074
30 to 39	732	317	136	59	1,244
40 to 49	781	412	174	36	1,403
50 to 59	819	438	137	37	1,431
60 to 69	829	429	124	36	1,418
70 to 79	772	324	161	34	1,291
≥80	856	275	149	28	1,308
≥20	774	327	141	46	1,288
All individuals	711	260	114	65	1,150

[a] Includes regular and low calorie fruit drinks, punches, and ades, including those made from powdered mix and frozen concentrate. Excludes fruit juices and carbonated drinks.

Source: USDA (1995).

Table 3-64. Number of Respondents That Consumed Tap Water at a Specified Daily Frequency

Population Group	Total *N*	None	Number of Glasses in a Day: 1–2	3–5	6–9	10–19	20+	DK
Overall	4,663	1,334	1,225	1,253	500	151	31	138
Sex								
Male	2,163	604	582	569	216	87	25	65
Female	2,498	728	643	684	284	64	6	73
Refused	2	2	-	-	-	-	-	-
Age (years)								
1 to 4	263	114	96	40	7	1	0	5
5 to 11	348	90	127	86	15	7	2	20
12 to 17	326	86	109	88	22	7	-	11
18 to 64	2,972	908	751	769	334	115	26	54
>64	670	117	127	243	112	20	2	42
Race								
White	3,774	1,048	1,024	1,026	416	123	25	92
Black	463	147	113	129	38	9	1	21
Asian	77	25	18	23	6	1	-	4
Some Others	96	36	18	22	6	7	2	5
Hispanic	193	63	42	40	28	10	2	7
Refused	60	15	10	13	6	1	1	9
Hispanic								
No	4,244	1,202	1,134	1,162	451	129	26	116
Yes	347	116	80	73	41	18	4	13
DK	26	5	6	7	4	3	-	1
Refused	46	11	5	11	4	1	1	8
Employment								
Full-time	2,017	637	525	497	218	72	18	40
Part-time	379	90	94	120	50	13	7	5
Not Employed	1,309	313	275	413	188	49	3	54
Refused	32	6	4	11	1	2	1	4
Education								
<High School	399	89	95	118	51	14	2	28
High School Graduate	1,253	364	315	330	132	52	13	37
<College	895	258	197	275	118	31	5	9
College Graduate	650	195	157	181	82	19	4	6
Post Graduate	445	127	109	113	62	16	3	12
Census Region								
Northeast	1,048	351	262	266	95	32	7	28
Midwest	1,036	243	285	308	127	26	9	33
South	1,601	450	437	408	165	62	11	57
West	978	290	241	271	113	31	4	20
Day of Week								
Weekday	3,156	864	840	862	334	96	27	106
Weekend	1,507	470	385	391	166	55	4	32
Season								
Winter	1,264	398	321	336	128	45	5	26
Spring	1,181	337	282	339	127	33	10	40
Summer	1,275	352	323	344	155	41	9	40
Fall	943	247	299	234	90	32	7	32
Asthma								
No	4,287	1,232	1,137	1,155	459	134	29	115
Yes	341	96	83	91	40	16	1	13
DK	35	6	5	7	1	1	1	10
Angina								
No	4,500	1,308	1,195	1,206	470	143	29	123
Yes	125	18	25	40	27	6	1	6
DK	38	8	5	7	3	2	1	9
Bronchitis/Emphysema								
No	4,424	1,280	1,161	1,189	474	142	29	124
Yes	203	48	55	58	24	9	1	5
DK	36	6	9	6	2	-	1	9

- = Missing data.
DK = Don't know.
N = Sample size.
Refused = Respondent refused to answer.

Source: U.S. EPA (1996).

Table 3-65. Number of Respondents That Consumed Juice Reconstituted with Tap Water at a Specified Daily Frequency

Population Group	Total *N*	Number of Glasses in a Day						
		None	1–2	3–5	6–9	10–19	20+	DK
Overall	4,663	1,877	1,418	933	241	73	21	66
Sex								
Male	2,163	897	590	451	124	35	17	33
Female	2,498	980	826	482	117	38	4	33
Refused	2	-	2	-	-	-	-	-
Age (years)								
1 to 4	263	126	71	48	11	4	1	2
5 to 11	348	123	140	58	12	2	1	11
12 to 17	326	112	118	63	18	7	1	4
18 to 64	2,972	1,277	817	614	155	46	16	30
>64	670	206	252	133	43	12	2	14
Race								
White	3,774	1,479	1,168	774	216	57	16	44
Black	463	200	142	83	15	9	1	7
Asian	77	33	27	15	1	-	-	0
Some Others	96	46	19	24	2	1	3	1
Hispanic	193	95	51	30	5	5	1	5
Refused	60	24	11	7	2	1	-	9
Hispanic								
No	4,244	1,681	1,318	863	226	64	17	49
Yes	347	165	87	61	14	7	4	7
DK	26	11	6	5	-	1	-	3
Refused	46	20	7	4	1	1	-	7
Employment								
Full-time	2,017	871	559	412	103	32	9	20
Part-time	379	156	102	88	19	7	2	5
Not Employed	1,309	479	426	265	75	20	7	21
Refused	32	15	4	4	2	1	-	3
Education								
<High School	399	146	131	82	25	7	2	4
High School Graduate	1,253	520	355	254	68	21	7	17
<College	895	367	253	192	47	18	5	11
College Graduate	650	274	201	125	31	7	1	5
Post Graduate	445	182	130	92	26	5	3	4
Census Region								
Northeast	1,048	440	297	220	51	13	4	15
Midwest	1,036	396	337	200	63	17	4	14
South	1,601	593	516	332	84	26	10	28
West	978	448	268	181	43	17	3	9
Day of Week								
Weekday	3,156	1,261	969	616	162	51	11	46
Weekend	1,507	616	449	307	79	22	10	20
Season								
Winter	1,264	529	382	245	66	23	4	10
Spring	1,181	473	382	215	54	19	8	17
Summer	1,275	490	389	263	68	18	6	28
Fall	943	385	265	210	53	13	3	11
Asthma								
No	4,287	1,734	1,313	853	216	69	20	55
Yes	341	130	102	74	25	3	1	5
DK	35	13	3	6	-	1	-	6
Angina								
No	4,500	1,834	1,362	900	231	67	20	59
Yes	125	31	53	25	7	5	1	1
DK	38	12	3	8	3	1	-	6
Bronchitis/Emphysema								
No	4,424	1,782	1,361	882	230	65	21	57
Yes	203	84	53	44	10	6	-	3
DK	36	11	4	7	1	2	-	6

- = Missing data.
DK = Don't know.
N = Sample size.
Refused = Respondent refused to answer.

Source: U.S. EPA (1996).

Table 3-66. Mean (standard error) Water and Drink Consumption (mL/kg-day) by Race/Ethnicity

Race/Ethnic Group	*N*	Plain Tap Water	Milk and Milk Drinks	Reconstituted Formula	RTF Formula	Baby Food	Juices and Carbonated Drinks	Non-Carbonated Drinks	Other	Total[a]
Black non-Hispanic	121	21 (1.7)	24 (4.6)	35 (6.0)	4 (2.0)	8 (1.6)	2 (0.7)	14 (1.3)	21 (1.7)	129 (5.7)
White non-Hispanic	620	13 (0.8)	23 (1.2)	29 (2.7)	8 (1.5)	10 (1.2)	1 (0.2)	11 (0.7)	18 (0.8)	113 (2.6)
Hispanic	146	15 (1.2)	23 (2.4)	38 (7.3)	12 (4.0)	10 (1.4)	1 (0.3)	10 (1.6)	16 (1.4)	123 (5.2)
Other	59	21 (2.4)	19 (3.7)	31 (9.1)	19 (11.2)	7 (4.0)	1 (0.5)	8 (2.0)	19 (3.2)	124 (10.6)

[a] Totals may be slightly different from the sums of all categories due to rounding.
N = Number of observations.
RTF = Ready-to-feed.
Note: Standard error shown in parentheses.

Source: Heller et al. (2000).

Table 3-67. Plain Tap Water and Total Water Consumption by Age, Sex, Region, Urbanicity, and Poverty Category

		Plain Tap Water (mL/kg-day)		Total Water (mL/kg-day)	
Variable	*N*	Mean	SE	Mean	SE
Age					
<12 months	296	11	1.0	130	4.6
12 to 24 months	650	18	0.8	108	1.7
Sex					
Male	475	15	1.0	116	4.1
Female	471	15	0.8	119	3.2
Region					
Northeast	175	13	1.4	121	6.3
Midwest	197	14	1.0	120	3.1
South	352	15	1.3	113	3.7
West	222	17	1.1	119	4.6
Urbanicity					
Urban	305	16	1.5	123	3.5
Suburban	446	13	0.9	117	3.1
Rural	195	15	1.2	109	3.9
Poverty category[a]					
0–1.30	289	19	1.5	128	2.6
1.31–3.50	424	14	1.0	117	4.2
>3.50	233	12	1.3	109	3.5
Total	946	15	0.6	118	2.3

[a] Poverty category represents family's annual incomes of 0–1.30, 1.31–3.50, and greater than 3.50 times the federal poverty level.

N = Number of observations.

SE = Standard error.

Source: Heller et al. (2000).

Table 3-68. Intake of Water From Various Sources in 2- to 13-Year-Old Participants of the DONALD Study, 1985-1999

Water Intake Source	Boys and Girls 2 to 3 years *N* = 858[b]	Boys and Girls 4 to 8 years *N* = 1,795[b]	Boys 9 to 13 years *N* = 541[b]	Girls 9 to 13 years *N* = 542[b]
	Mean			
Water in Food (mL/day)[a]	365 (33)[c]	487 (36)	673 (36)	634 (38)
Beverages (mL/day)[a]	614 (55)	693 (51)	969 (51)	823 (49)
Milk (mL/day)[a]	191 (17)	177 (13)	203 (11)	144 (9)
Mineral water (mL/day)[a]	130 (12)	179 (13)	282 (15)	242 (15)
Tap water (mL/day)[a]	45 (4)	36 (3)	62 (3)	56 (3)
Juice (mL/day)[a]	114 (10)	122 (0)	133 (7)	138 (8)
Soft drinks (mL/day)[a]	57 (5)	111 (8)	203 (11)	155 (9)
Coffee/tea (mL/day)[a]	77 (7)	69 (5)	87 (4)	87 (5)
	Mean ± SD			
Total water intake[a,d] (mL/day)	1,114 ± 289	1,363 ± 333	1,891 ± 428	1,676 ± 386
Total water intake[a,d] (mL/kg-day)	78 ± 22	61 ± 13	49 ± 11	43 ± 10
Total water intake[a,d] (mL/kcal-day)	1.1 ± 0.3	0.9 ± 0.2	1.0 ± 0.2	1.0 ± 0.2

[a] Converted from g/day, g/kg-day, or g/kcal-day; 1 g = 1 mL.
[b] *N* = Number of records.
[c] Percent of total water shown in parentheses.
[d] Total water = water in food + beverages + oxidation.
SD = Standard deviation.

Source: Sichert-Hellert et al. (2001).

Table 3-69. Mean (±standard error) Fluid Intake (mL/kg-day) by Children Aged 1 to 10 Years, NHANES III, 1988–1994

	Total Sample (*N* = 7,925)	Sample with Temperature Information (*N* = 3,869)	Sample without Temperature Information (*N* = 4,056)
Total fluid	84 ± 1.0	84 ± 1.0	85 ± 1.4
Plain water	27 ± 0.8	27 ± 1.0	26 ± 1.1
Milk	18 ± 0.3	18 ± 0.6	18 ± 0.4
Carbonated drinks	6 ± 0.2	5 ± 0.3	6 ± 0.3
Juice	12 ± 0.3	11 ± 0.6	12 ± 0.4

N = Number of observations.

Source: Sohn et al. (2001).

Table 3-70. Estimated Mean (±standard error) Amount of Total Fluid and Plain Water Intake Among Children[a] Aged 1 to 10 Years by Age, Sex, Race/Ethnicity, Poverty Income Ratio, Region, and Urbanicity (NHANES III, 1988–1994)

	N	Total Fluid		Plain Water	
		mL/day	mL/kg-day	mL/day	mL/kg-day
Age (years)					
1	578	1,393 ± 31	124 ± 2.9	298 ± 19	26 ± 1.8
2	579	1,446 ± 31	107 ± 2.3	430 ± 26	32 ± 1.9
3	502	1,548 ± 75	100 ± 4.6	482 ± 27	31 ± 1.8
4	511	1,601 ± 41	91 ± 2.8	517 ± 23	29 ± 1.3
5	465	1,670 ± 54	84 ± 2.3	525 ± 36	26 ± 1.7
6	255	1,855 ± 125	81 ± 4.9	718 ± 118	31 ± 4.7
7	235	1,808 ± 66	71 ± 2.3	674 ± 46	26 ± 1.9
8	247	1,792 ± 37	61 ± 1.8	626 ± 37	21 ± 1.2
9	254	2,113 ± 78	65 ± 2.1	878 ± 59	26 ± 1.4
10	243	2,051 ± 97	58 ± 2.4	867 ± 74	24 ± 2.0
Sex					
Male	1,974	1,802 ± 30	86 ± 1.8	636 ± 32	29 ± 1.3
Female	1,895	1,664 ± 24	81 ± 1.5	579 ± 26	26 ± 1.0
Race/ethnicity					
White	736	1,653 ± 26	79 ± 1.8	552 ± 34	24 ± 0.3
Black	1,122	1,859 ± 42	88 ± 1.8	795 ± 36	36 ± 1.5
Mexican American	1,728	1,817 ± 25	89 ± 1.7	633 ± 23	29 ± 1.1
Other	283	1,813 ± 47	90 ± 4.2	565 ± 39	26 ± 1.7
Poverty/income ratio[b]					
Low	1,868	1,828 ± 32	93 ± 2.6	662 ± 27	32 ± 1.3
Medium	1,204	1,690 ± 31	80 ± 1.6	604 ± 35	26 ± 1.4
High	379	1,668 ± 54	76 ± 2.5	533 ± 41	22 ± 1.7
Region[c,d]					
Northeast	679	1,735 ± 31	87 ± 2.3	568 ± 52	26 ± 2.1
Midwest	699	1,734 ± 45	84 ± 1.5	640 ± 54	29 ± 1.8
South	869	1,739 ± 31	83 ± 2.2	613 ± 24	28 ± 1.3
West	1,622	737 ± 25	81 ± 1.7	624 ± 44	27 ± 1.9
Urban/rural[d]					
Urban	3,358	1,736 ± 18	84 ± 1.0	609 ± 29	27 ± 1.1
Rural	511	1,737 ± 19	84 ± 4.3	608 ± 20	28 ± 1.2
Total	3,869	1,737 ± 15	84 ± 1.1	609 ± 24	27 ± 1.0

[a] Children for whom temperature data were obtained.

[b] Based on ratio of household income to federal poverty threshold. Low: ≤1.300; medium: 1.301–3.500; high: ≥3.501.

[c] All variables except for Region and Urban/rural showed statistically significant differences for both total fluid and plain water intake by Bonferroni multiple comparison method.

[d] Northeast = Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont;
Midwest = Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin;
South = Alabama, Arkansas, Delaware, District of Columbia, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, West Virginia;
West = Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, Wyoming.

N = Number of observations.

Source: Sohn et al. (2001).

Table 3-71. Tap Water Intake in Breast-Fed and Formula-Fed Infants and Mixed-Fed Young Children at Different Age Points

Age	N[a]	Tap Water Intake[b] (mL/day)					Tap Water Intake[b] (mL/kg-day)											
		Total					Total						From Household[c]			From Manufacturing[d]		
		Mean	SD	Median	p95	Max	Mean	SD	Median	p95	Max	%[e]	Mean	SD	%[f]	Mean	SD	%[f]
Breast-fed																		
1 year, total	300	130	180	50	525	1,172	17	24**	6	65	150	17	15	23**	85	2.4	4.7**	15
3 months	111	67	167	0	493	746	10	25**	0	74	125	10	10	25**	97	0.3	1.9**	3
6 months	124	136	150	68	479	634	18	20**	8	5`8	85	18	14	19**	79	3.8	6.3*	21
9 months	47	254	218	207	656	1,172	30	27**	23	77	150	28	26	27**	87	3.7	3.4	13
12 months	18	144	170	85	649	649	15	18**	9	66	66	19	13	18**	86	2.2	2.1	14
Formula-fed																		
1 year, total	758	441	244	440	828	1,603	53	33	49	115	200	51	49	33	92	4.0	8.0	8
3 months	78	662	154	673	874	994	107	23	107	147	159	93	103	28	97	3.4	17.9	3
6 months	141	500	178	519	757	888	63	23	65	99	109	64	59	25	92	4.8	8.0	8
9 months	242	434	236	406	839	1,579	49	27	45	94	200	50	44	27	91	4.5	6.3	9
12 months	297	360	256	335	789	1,603	37	26	32	83	175	39	33	25	91	3.3	3.7	9
Mixed-fed																		
1 to 3 years, total	904	241	243	175	676	2,441	19	20	14	56	203	24	15	20	78	3.9	5.5	22
18 months	277	280	264	205	828	1,881	25	23	18	70	183	28	22	23	88	3.0	4.1	12
24 months	292	232	263	158	630	2,441	18	21	12	49	203	23	15	21	80	3.7	5.0	20
36 months	335	217	199	164	578	1,544	14	13	11	36	103	22	9	12	66	4.9	6.6	34

[a] Numbers of 3-day diet records.
[b] Total tap water = tap water from the household and tap water from food manufacturing. Converted from g/day and g/kg-day; 1 g = 1 mL.
[c] Tap water from household = tap water from the household tap consumed directly as a beverage or used to prepare foods and beverages.
[d] Tap water from food = manufacturing tap water from the industrial food production used for the preparation of foods (bread, butter/margarine, tinned fruit, vegetables and legumes, ready to serve meals, commercial weaning food) and mixed beverages (lemonade, soft drinks).
[e] Mean as a percentage of total water.
[f] Mean as a percentage of total tap water.
* Significantly different from formula-fed infants, $p < 0.05$.
** Significantly different from formula-fed infants, $p < 0.0001$.
SD = Standard Deviation.
p95 = 95th percentile.

Source: Hilbig et al. (2002).

Table 3-72. Percentage of Subjects Consuming Beverages and Mean Daily Beverage Intakes (mL/day) for Children With Returned Questionnaires

Age at Questionnaire	6 Months	9 Months	12 Months	16 Months	20 Months	24 Months	6 to 24 Months[a]
Actual Age (Months)	6.29 ± 0.35	9.28 ± 0.35	12.36 ± 0.46	16.31 ± 0.49	20.46 ± 0.57	24.41 ± 0.53	-
N[b]	677	681	659	641	632	605	585[c]
Human Milk[d]	30	19	11	5	3	0	-
Infant Formula[e]							
%[d]	68	69	29	4	2	0	67[g]
mL/day[f]	798 ± 234	615 ± 328	160 ± 275	12 ± 77	9 ± 83	-	207 ± 112
Cows' Milk[e]							
%[d]	5	25	79	91	93	97	67[g]
mL/day[f]	30 ± 145	136 ± 278	470 ± 310	467 ± 251	402 ± 237	358 ± 225	355 ± 163
Formula and Cows' Milk[e]							
%[d]	70	81	88	92	94	98	67[g]
mL/day[f]	828 ± 186	751 ± 213	630 ± 245	479 ± 248	411 ± 237	358 ± 228	562 ± 154
Juice and Juice Drinks							
%[d]	55	73	89	94	95	93	99[h]
mL/day[f]	65 ± 95	103 ± 112	169 ± 151	228 ± 166	269 ± 189	228 ± 172	183 ± 103
Water							
%[d]	36	59	75	87	90	94	99[h]
mL/day[f]	27 ± 47	53 ± 71	92 ± 109	124 ± 118	142 ± 127	145 ± 148	109 ± 74
Other Beverages[i]							
%[d]	1	9	23	42	62	86	80[h]
mL/day[f]	3 ± 18	6 ± 27	27 ± 71	53 ± 109	83 ± 121	89 ± 133	44 ± 59
Total Beverages mL/day[e,f,j]	934 ± 219	917 ± 245	926 ± 293	887 ± 310	908 ± 310	819 ± 299	920 ± 207

[a] Cumulative number of children and percentage of children consuming beverage and beverage intakes for the 6- through 24-month period.
[b] Number of children with returned questionnaires at each time period.
[c] Number of children with cumulative intakes for 6- through 24-month period.
[d] Percentage of children consuming beverage.
[e] Children are not included when consuming human milk.
[f] Mean standard deviation of beverage intake. Converted from ounces/day; 1 fluid ounce = 29.57 mL.
[g] Percentage of children consuming beverage during 6- through 24-month period. Children who consumed human milk are not included.
[h] Percentage of children consuming beverage during 6- through 24-month period.
[i] Other beverages include non-juice beverages (e.g., carbonated beverages, Kool-Aid).
[j] Total beverages includes all beverages except human milk.
\- Indicates there are insufficient data.

Source: Marshall et al. (2003b).

Table 3-73. Mean (±standard deviation) Daily Beverage Intakes Reported on Beverage Frequency Questionnaire and 3-Day Food and Beverage Diaries

Beverage	Age											
	6 months (N = 240)			12 months (N = 192)			3 years (N = 129)			5 years (N = 112)		
	Questionnaire	Diary		Questionnaire	Diary		Questionnaire	Diary		Questionnaire	Diary	
	mL/day[a]		%[b]	mL/day[a]		%[b]	mL/day[a]		%[b]	mL/day[a]		%[b]
Human milk	204 ± 373	195 ± 358	28.0	9 ± 21	56 ± 225	12.6	NA[c]	NA	-	NA	NA	-
Infant formula	609 ± 387	603 ± 364	85.8	180 ± 290	139 ± 251	37.0	NA	NA	-	NA	NA	-
Cows' milk	24 ± 124	24 ± 124	6.7	429 ± 349	408 ± 331	90.4	316 ± 216	358 ± 216	100	319 ± 198	325 ± 177	98.2
Juice/juice drinks	56 ± 124	33 ± 59	57.5	151 ± 136	106 ± 101	92.2	192 ± 169	198 ± 169	96.9	189 ± 169	180 ± 163	95.5
Liquid soft drinks	6 ± 68	0 ± 0	1.3	9 ± 30	3 ± 15	20.9	62 ± 71	74 ± 101	74.2	74 ± 95	101 ± 121	82.1
Powdered soft drinks	0 ± 18	0 ± 0	0.4	12 ± 47	3 ± 18	10.5	62 ± 115	47 ± 101	51.2	74 ± 124	47 ± 95	52.7
Water	44 ± 80	30 ± 53	61.7	127 ± 136	80 ± 109	84.9	177 ± 204	136 ± 177	95.3	240 ± 242	169 ± 183	99.1
Total	940 ± 319	896 ± 195	100	905 ± 387	804 ± 284	100	795 ± 355	816 ± 299	100	896 ± 399	819 ± 302	100

[a] Mean standard deviation of all subjects. Converted from ounces/day; 1 fluid ounce = 29.57 mL.
[b] Percent of subjects consuming beverage on either questionnaire or diary.
[c] NA = not applicable.
N = Number of observations.
\- Indicates there are insufficient data to calculate percentage.

Source: Marshall et al. (2003a).

Table 3-74. Consumption of Beverages by Infants and Toddlers (Feeding Infants and Toddlers Study)

Beverage Category	Age (months)											
	4 to 6 Months (*N* = 862)		7 to 8 Months (*N* = 483)		9 to 11 Months (*N* = 679)		12 to 14 Months (*N* = 374)		15 to 18 Months (*N* = 308)		19 to 24 Months (*N* = 316)	
	Consumers %[a]	Mean ± SD mL/day[b]	Consumers %[a]	Mean ± SD mL/day[b]	Consumers %[a]	Mean ± SD mL/day[b]	Consumers %[a]	Mean ± SD mL/day[b]	Consumers %[a]	Mean ± SD mL/day[b]	Consumers %[a]	Mean ± SD mL/day[b]
Total Milks[c]	100	778 ± 257	100	692 ± 257	99.7	659 ± 284	98.2	618 ± 293	94.2	580 ± 305	93.4	532 ± 281
100% Juice[d]	21.3	121 ± 89	45.6	145 ± 109	55.3	160 ± 127	56.2	186 ± 145	57.8	275 ± 189	61.6	281 ± 189
Fruit Drinks[e]	1.6	101 ± 77	7.1	98 ± 77	12.4	157 ± 139	29.1	231 ± 186	38.6	260 ± 231	42.6	305 ± 308
Carbonated	0.1	86 ± 0	1.1	6 ± 9	1.7	89 ± 92	4.5	115 ± 83	11.2	157 ± 106	11.9	163 ± 172
Water	33.7	163 ± 231	56.1	174 ± 219	66.9	210 ± 234	72.2	302 ± 316	74.0	313 ± 260	77.0	337 ± 245
Other[f]	1.4	201 ± 192	2.2	201 ± 219	3.5	169 ± 166	6.6	251 ± 378	12.2	198 ± 231	11.2	166 ± 248
Total beverages	100	863 ± 254	100	866 ± 310	100	911 ± 361	100	1,017 ± 399	100	1,079 ± 399	100	1,097 ± 482

[a] Weighted percentages, adjusted for over sampling, non-response, and under-representation of some racial and ethnic groups.
[b] Amounts consumed only by those children who had a beverage from this beverage category. Converted from ounces/day; 1 fluid ounce = 29.57 mL.
[c] Includes human milk, infant formula, cows' milk, soy milk, and goats' milk.
[d] Fruit or vegetable juices with no added sweeteners.
[e] Includes beverages with less than 100% juice and often with added sweeteners; some were fortified with one or more nutrients.
[f] "Other" beverages category included tea, cocoa, and similar dry milk beverages, and electrolyte replacement beverages for infants.
N = Number of observations.
SD = Standard Deviation.

Source: Skinner et al. (2004).

Table 3-75. Per Capita Estimates of Direct and Indirect Water Intake From All Sources by Pregnant, Lactating, and Childbearing Age Women (mL/kg-day)

		Mean			90th Percentile			95th Percentile		
			90% CI			90% BI			90% BI	
Women Categories	Sample Size	Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound
Pregnant	69	21*	19*	22*	39*	33*	46*	44*	38*	46*
Lactating	40	21*	15*	28*	53*	44*	55*	55*	52*	57*
Non-pregnant, Non-lactating Ages 15 to 44 years	2,166	19	19	20	35	35	36	36	46	47

NOTE: Source of data: 1994–1996, 1998 USDA CSFII; estimates are based on 2-day averages; interval estimates may involve aggregation of variance estimation units when data are too sparse to support estimation of the variance; all estimates exclude commercial and biological water.

90% CI = 90% confidence intervals for estimated means; 90% BI = 90% Bootstrap intervals for percentile estimates using bootstrap method with 1,000 replications.

* The sample size does not meet minimum reporting requirements to make statistically reliable estimates as described in the *Third Report on Nutrition Monitoring in the United States*, 1994–1996 (FASEB/LSRO, 1995).

Source: Kahn and Stralka (2008) (Based on CSFII 1994–1996 and 1998).

Table 3-76. Per Capita Estimates of Direct and Indirect Water Intake From All Sources by Pregnant, Lactating, and Childbearing Age Women (mL/day)

		Mean			90th Percentile			95th Percentile		
			90% CI			90% BI			90% BI	
Women Categories	Sample Size	Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound
Pregnant	70	1,318*	1,199*	1,436*	2,336*	1,851*	3,690*	2,674*	2,167*	3,690*
Lactating	41	1,806*	1,374*	2,238*	3,021*	2,722*	3,794*	3,767*	3,452*	3,803*
Non-pregnant, Non-lactating Aged 15 to 44	2,221	1,243	1,193	1,292	2,336	2,222	2,488	2,937	2,774	3,211

NOTE: Source of data: 1994–1996, 1998 USDA CSFII; estimates are based on 2-day averages; interval estimates may involve aggregation of variance estimation units when data are too sparse to support estimation of the variance; all estimates exclude commercial and biological water.

90% CI = 90% confidence intervals for estimated means; 90% BI = 90% Bootstrap intervals for percentile estimates using bootstrap method with 1,000 replications.

* The sample size does not meet minimum reporting requirements to make statistically reliable estimates as described in the *Third Report on Nutrition Monitoring in the United States*, 1994–1996 (FASEB/LSRO, 1995).

Source: Kahn and Stralka (2008) (Based on CSFII 1994–1996 and 1998).

Table 3-77. Per Capita Estimated Direct and Indirect Community Water Ingestion by Pregnant, Lactating, and Childbearing Age Women (mL/kg-day)

		Mean			90th Percentile			95th Percentile		
			90% CI			90% BI			90% BI	
Women Categories	Sample Size	Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound
Pregnant	69	13*	11*	14*	31*	28*	46*	43*	33*	46*
Lactating	40	21*	15*	28*	53*	44*	55*	55*	52*	57*
Non-pregnant, Non-lactating Ages 15 to 44 years	2,166	14	14	15	31	30	32	38	36	39

NOTE: Source of data: 1994–1996, 1998 USDA CSFII; estimates are based on 2-day averages; interval estimates may involve aggregation of variance estimation units when data are too sparse to support estimation of the variance; all estimates exclude commercial and biological water.

90% CI = 90% confidence intervals for estimated means; 90% B.I. = 90% Bootstrap intervals for percentile estimates using bootstrap method with 1,000 replications.

* The sample size does not meet minimum reporting requirements to make statistically reliable estimates as described in the *Third Report on Nutrition Monitoring in the United States*, 1994–1996 (FASEB/LSRO, 1995).

Source: Kahn and Stralka (2008) (Based on CSFII 1994–1996 and 1998).

Table 3-78. Per Capita Estimated Direct and Indirect Community Water Ingestion by Pregnant, Lactating, and Childbearing Age Women (mL/day)

		Mean			90th Percentile			95th Percentile		
			90% CI			90% BI			90% BI	
Women Categories	Sample Size	Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound
Pregnant	70	819*	669*	969*	1,815*	1,479*	2,808*	2,503*	2,167*	3,690*
Lactating	41	1,379*	1,021*	1,737*	2,872*	2,722*	3,452*	3,434*	2,987*	3,803*
Non-pregnant, Non-lactating Ages 15 to 44 years	2,221	916	882	951	1,953	1,854	2,065	2,575	2,403	2,908

NOTE: Source of data: 1994–1996, 1998 USDA CSFII; estimates are based on 2-day averages; interval estimates may involve aggregation of variance estimation units when data are too sparse to support estimation of the variance; all estimates exclude commercial and biological water.

90% CI = 90% confidence intervals for estimated means; 90% BI = 90% Bootstrap intervals for percentile estimates using bootstrap method with 1,000 replications.

* The sample size does not meet minimum reporting requirements to make statistically reliable estimates as described in the *Third Report on Nutrition Monitoring in the United States*, 1994–1996 (FASEB/LSRO, 1995).

Source: Kahn and Stralka (2008) (Based on CSFII 1994–1996 and 1998).

Table 3-79. Estimates of Consumers-Only Direct and Indirect Water Intake From All Sources by Pregnant, Lactating, and Childbearing Age Women (mL/kg-day)

		Mean			90th Percentile			95th Percentile		
			90% CI			90% BI			90% BI	
Women Categories	Sample Size	Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound
Pregnant	69	21*	19*	22*	39*	33*	46*	44*	38*	46*
Lactating	40	28*	19*	38*	53*	44*	57*	57*	52*	58*
Non-pregnant, Non-lactating Ages 15 to 44 years	2,149	19	19	20	35	34	37	46	42	48

NOTE: Source of data: 1994–1996, 1998 USDA CSFII; estimates are based on 2-day averages; interval estimates may involve aggregation of variance estimation units when data are too sparse to support estimation of the variance; all estimates exclude commercial and biological water.

90% CI = 90% confidence intervals for estimated means; 90% BI = 90% Bootstrap intervals for percentile estimates using bootstrap method with 1,000 replications.

* The sample size does not meet minimum reporting requirements to make statistically reliable estimates as described in the *Third Report on Nutrition Monitoring in the United States*, 1994–1996 (FASEB/LSRO, 1995).

Source: Kahn and Stralka (2008) (Based on CSFII 1994–1996 and 1998).

Table 3-80. Estimates of Consumers-Only Direct and Indirect Water Intake From All Sources by Pregnant, Lactating, and Childbearing Age Women (mL/day)

		Mean			90th Percentile			95th Percentile		
			90% CI			90% BI			90% BI	
Women Categories	Sample Size	Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound
Pregnant	70	1,318*	1,199*	1,436*	2,336*	1,851*	3,690*	2,674*	2,167*	3,690*
Lactating	41	1,806*	1,374*	2,238*	3,021*	2,722*	3,794*	3,767*	3,452*	3,803*
Non-pregnant, Non-lactating Ages 15 to 44 years	2,203	1,252	1,202	1,303	2,338	2,256	2,404	2,941	2,834	3,179

NOTE: Source of data: 1994–1996, 1998 USDA CSFII; estimates are based on 2-day averages; interval estimates may involve aggregation of variance estimation units when data are too sparse to support estimation of the variance; all estimates exclude commercial and biological water.

90% CI = 90% confidence intervals for estimated means; 90% BI = 90% Bootstrap intervals for percentile estimates using bootstrap method with 1,000 replications.

* The sample size does not meet minimum reporting requirements to make statistically reliable estimates as described in the *Third Report on Nutrition Monitoring in the United States*, 1994–1996 (FASEB/LSRO, 1995).

Source: Kahn and Stralka (2008) (Based on CSFII 1994–1996 and 1998).

Table 3-81. Consumers-Only Estimated Direct and Indirect Community Water Ingestion by Pregnant, Lactating, and Childbearing Age Women (mL/kg-day)

		Mean			90th Percentile			95th Percentile		
			90% CI			90% BI			90% BI	
Women Categories	Sample Size	Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound
Pregnant	65	14*	12*	15*	33*	29*	46*	43*	33*	46*
Lactating	33	26*	18*	18*	54*	44*	55*	55*	53*	57*
Non-pregnant, Non-lactating Ages 15 to 44 years	2,028	15	14	16	32	31	33	38	36	42

NOTE: Source of data: 1994–1996, 1998 USDA CSFII; estimates are based on 2-day averages; interval estimates may involve aggregation of variance estimation units when data are too sparse to support estimation of the variance; all estimates exclude commercial and biological water.

90% CI = 90% confidence intervals for estimated means; 90% BI = 90% Bootstrap intervals for percentile estimates using bootstrap method with 1,000 replications.

* The sample size does not meet minimum reporting requirements to make statistically reliable estimates as described in the *Third Report on Nutrition Monitoring in the United States*, 1994–1996 (FASEB/LSRO, 1995).

Source: Kahn and Stralka (2008) (Based on CSFII 1994–1996 and 1998).

Table 3-82. Consumers-Only Estimated Direct and Indirect Community Water Ingestion by Pregnant, Lactating, and Childbearing Age Women (mL/day)

		Mean			90th Percentile			95th Percentile		
			90% CI			90% BI			90% BI	
Women Categories	Sample Size	Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound	Estimate	Lower Bound	Upper Bound
Pregnant	65	872*	728*	1,016*	1,844*	1,776*	3,690*	2,589*	2,167*	3,690*
Lactating	34	1,665*	1,181*	2,148*	2,959*	2,722*	3,452*	3,588*	2,987*	4,026*
Non-pregnant, Non-lactating Ages 15 to 44 years	2,077	976	937	1,014	2,013	1,893	2,065	2,614	2,475	2,873

NOTE: Source of data: 1994–1996, 1998 USDA CSFII; estimates are based on 2-day averages; interval estimates may involve aggregation of variance estimation units when data are too sparse to support estimation of the variance; all estimates exclude commercial and biological water.

90% CI = 90% confidence intervals for estimated means; 90% BI = 90% Bootstrap intervals for percentile estimates using bootstrap method with 1,000 replications.

* The sample size does not meet minimum reporting requirements to make statistically reliable estimates as described in the *Third Report on Nutrition Monitoring in the United States*, 1994–1996 (FASEB/LSRO, 1995).

Source: Kahn and Stralka (2008) (Based on CSFII 1994–1996 and 1998).

Table 3-83. Total Fluid Intake of Women 15 to 49 Years Old

Reproductive Status[a]	Mean	Standard Deviation	Percentile Distribution						
			5	10	25	50	75	90	95
mL/day									
Control	1,940	686	995	1,172	1,467	1,835	2,305	2,831	3,186
Pregnant	2,076	743	1,085	1,236	1,553	1,928	2,444	3,028	3,475
Lactating	2,242	658	1,185	1,434	1,833	2,164	2,658	3,169	3,353
mL/kg-day									
Control	32.3	12.3	15.8	18.5	23.8	30.5	38.7	48.4	55.4
Pregnant	32.1	11.8	16.4	17.8	17.8	30.5	40.4	48.9	53.5
Lactating	37.0	11.6	19.6	21.8	21.8	35.1	45.0	53.7	59.2

[a] Number of observations: non-pregnant, non-lactating controls (N = 6,201); pregnant (N = 188); lactating (N = 77).

Source: Ershow et al. (1991).

Table 3-84. Total Tap Water Intake of Women 15 to 49 Years Old									
Reproductive Status[a]	Mean	Standard Deviation	Percentile Distribution						
			5	10	25	50	75	90	95
mL/day									
Control	1,157	635	310	453	709	1,065	1,503	1,983	2,310
Pregnant	1,189	699	274	419	713	1,063	1,501	2,191	2,424
Lactating	1,310	591	430	612	855	1,330	1,693	1,945	2,191
mL/kg-day									
Control	19.1	10.8	5.2	7.5	11.7	17.3	24.4	33.1	39.1
Pregnant	18.3	10.4	4.9	5.9	10.7	16.4	23.8	34.5	39.6
Lactating	21.4	9.8	7.4	9.8	14.8	20.5	26.8	35.1	37.4
Fraction of daily fluid intake that is tap water (%)									
Control	57.2	18.0	24.6	32.2	45.9	59.0	70.7	79.0	83.2
Pregnant	54.1	18.2	21.2	27.9	42.9	54.8	67.6	76.6	83.2
Lactating	57.0	15.8	27.4	38.0	49.5	58.1	65.9	76.4	80.5

a Number of observations: non-pregnant, non-lactating controls (N = 6,201); pregnant (N = 188); lactating (N = 77).

Source: Ershow et al. (1991).

Table 3-85. Total Fluid (mL/day) Derived from Various Dietary Sources by Women Aged 15 to 49 Years[a]									
Sources	Control Women			Pregnant Women			Lactating Women		
	Mean[b]	Percentile 50	Percentile 95	Mean[b]	Percentile 50	Percentile 95	Mean[b]	Percentile 50	Percentile 95
Drinking Water	583	480	1,440	695	640	1,760	677	560	1,600
Milk and Milk Drinks	162	107	523	308	273	749	306	285	820
Other Dairy Products	23	8	93	24	9	93	36	27	113
Meats, Poultry, Fish, Eggs	126	114	263	121	104	252	133	117	256
Legumes, Nuts, and Seeds	13	0	77	18	0	88	15	0	72
Grains and Grain Products	90	65	257	98	69	246	119	82	387
Citrus and Non-citrus Fruit Juices	57	0	234	69	0	280	64	0	219
Fruits, Potatoes, Vegetables, Tomatoes	198	171	459	212	185	486	245	197	582
Fats, Oils, Dressings, Sugars, Sweets	9	3	41	9	3	40	10	6	50
Tea	148	0	630	132	0	617	253	77	848
Coffee and Coffee Substitutes	291	159	1,045	197	0	955	205	80	955
Carbonated Soft Drinks[c]	174	110	590	130	73	464	117	57	440
Non-carbonated Soft Drinks[c]	38	0	222	48	0	257	38	0	222
Beer	17	0	110	7	0	0	17	0	147
Wine Spirits, Liqueurs, Mixed Drinks	10	0	66	5	0	25	6	0	59
All Sources	1,940	NA	NA	2,076	NA	NA	2,242	NA	NA

a Number of observations: non-pregnant, non-lactating controls (N = 6,201); pregnant (N = 188); lactating (N = 77).

b Individual means may not add to all-sources total due to rounding.

c Includes regular, low-calorie, and non-calorie soft drinks.

NA: Not appropriate to sum the columns for the 50th and 95th percentiles of intake.

Source: Ershow et al. (1991).

Table 3-86. Total Tap Water and Bottled Water Intake by Pregnant Women (L/day)

Variables	Cold Tap Water		Bottled Water	
	N	Mean (SD)	*N*	Mean (SD)
Demographics				
Home	2,293	1.3 (1.2)	[a]	[a]
Work	2,295	0.4 (0.6)	[a]	[a]
Total	2,293	1.7 (1.4)	2,284	0.6 (0.9)
Geographic Region				
Site 1	1,019	1.8 (1.4)	1,016	0.5 (0.9)
Site 2	864	1.9 (1.4)	862	0.4 (0.7)
Site 3	410	1.1 (1.3)	406	1.1 (1.2)
Season				
Winter	587	1.6 (1.3)	584	0.6 (1.0)
Spring	622	1.7 (1.4)	622	0.6 (1.0)
Summer	566	1.8 (1.6)	560	0.6 (0.9)
Fall	518	1.8 (1.5)	518	0.5 (0.9)
Age at LMP[b]				
17 to 25	852	1.6 (1.4)	848	0.6 (1.0)
26 to 30	714	1.8 (1.5)	710	0.6 (1.0)
31 to 35	539	1.7 (1.3)	538	0.5 (0.8)
≥36	188	1.8 (1.4)	188	0.5 (0.9)
Education				
≤High school	691	1.5 (1.5)	687	0.6 (1.0)
Some college	498	1.7 (1.5)	496	0.6 (1.0)
≥4-year college	1,103	1.8 (1.3)	1,100	0.5 (0.9)
Race/ethnicity				
White, non-Hispanic	1,276	1.8 (1.4)	1,273	0.5 (0.9)
Black, non-Hispanic	727	1.6 (1.5)	722	0.6 (0.9)
Hispanic, any race	204	1.1 (1.3)	202	1.1 (1.2)
Other	84	1.9 (1.5)	85	0.5 (0.9)
Marital Status				
Single, never married	719	1.6 (1.5)	713	0.6 (1.0)
Married	1,497	1.8 (1.4)	1,494	0.5 (0.9)
Other	76	1.7 (1.9)	76	0.5 (0.9)
Annual Income ($)				
≤40,000	967	1.6 (1.5)	962	0.6 (1.0)
40,000–80,000	730	1.8 (1.4)	730	0.5 (0.9)
>80,000	501	1.7 (1.3)	499	0.5 (0.9)
Employment				
No	681	1.7 (1.5)	679	0.5 (0.9)
Yes	1,611	1.7 (1.4)	1,604	0.6 (0.9)
BMI				
Low	268	1.6 (1.3)	267	0.6 (1.0)
Normal	1,128	1.7 (1.4)	1,123	0.5 (0.9)
Overweight	288	1.7 (1.5)	288	0.6 (0.9)
Obese	542	1.8 (1.6)	540	0.6 (1.0)

Table 3-86. Total Tap Water and Bottled Water Intake by Pregnant Women (L/day) (continued)

Variables	Cold Tap Water		Bottled Water	
	N	Mean (SD)	*N*	Mean (SD)
Diabetes				
No diabetes	2,221	1.7 (1.4)	2,213	0.6 (0.9)
Regular diabetes	17	2.6 (2.1)	17	0.4 (0.8)
Gestational diabetes	55	1.6 (1.6)	54	0.6 (1.0)
Nausea during pregnancy				
No	387	1.6 (1.4)	385	0.6 (1.0)
Yes	1,904	1.7 (1.4)	1,897	0.6 (0.9)
Pregnancy history				
No prior pregnancy	691	1.7 (1.4)	685	0.6 (1.0)
Prior pregnancy with no SAB[c]	1,064	1.7 (1.4)	1,063	0.5 (0.9)
Prior pregnancy with SAB	538	1.8 (1.5)	536	0.6 (1.0)
Caffeine				
0 mg/day	578	1.8 (1.5)	577	0.6 (1.0)
1–150 mg/day	522	1.6 (1.3)	522	0.5 (0.8)
151–300 mg/day	433	1.6 (1.4)	433	0.6 (0.9)
>300 mg/day	760	1.7 (1.5)	752	0.6 (1.0)
Vitamin use				
No	180	1.4 (1.4)	176	0.5 (0.8)
Yes	2,113	1.7 (1.4)	2,108	0.6 (0.9)
Smoking				
Non-smoker	2,164	1.7 (1.4)	2,155	0.6 (0.9)
<10 cigarettes/day	84	1.8 (1.5)	84	0.8 (1.3)
≥10 cigarettes/day	45	1.8 (1.6)	45	0.4(0.7)
Alcohol use				
No	2,257	1.7 (1.4)	2,247	0.6 (0.9)
Yes	36	1.6 (1.2)	37	0.6 (0.8)
Recreational exercise				
No	1,061	1.5 (1.4)	1,054	0.6 (0.9)
Yes	1,232	1.8 (1.4)	1,230	0.6 (1.0)
Illicit drug use				
No	2,024	1.7 (1.4)	2,017	0.6 (0.9)
Yes	268	1.7 (1.5)	266	0.6 (1.0)

[a] Data are not reported in the source document.
[b] LMP = Age of Last Menstrual Period.
[c] SAB = Spontaneous abortion.
N = Number of observations.
SD = Standard deviation.

Source: Forssen et al. (2007).

Table 3-87. Percentage of Mean Water Intake Consumed as Unfiltered and Filtered Tap Water by Pregnant Women

Variables		Cold Unfiltered Tap Water	Cold Filtered Tap Water	Bottled Water
	N	%	%	%
Total	2,280	52	19	28
Geographic Region				
Site 1	1,014	46	28	26
Site 2	860	67	13	19
Site 3	406	37	10	53
Season				
Winter	583	52	19	29
Spring	621	53	19	28
Summer	559	50	20	29
Fall	517	54	19	26
Age at LMP[a]				
≤25	845	55	11	33
26–30	709	49	22	28
31–35	538	51	27	22
≥36	188	53	22	25
Education				
≤High school	685	56	8	34
Some college	495	53	16	30
≥4-year college	1,099	49	27	23
Race/ethnicity				
White, non-Hispanic	1,272	50	26	23
Black, non-Hispanic	720	60	9	30
Hispanic, any race	202	37	9	54
Other	84	48	27	25
Marital Status				
Single, never married	711	57	9	33
Married	1,492	50	25	25
Other	76	57	9	34
Annual Income ($)				
≤40,000	960	56	11	33
40,000–80,000	728	51	24	24
>80,000	499	45	29	25
Employment				
No	678	52	21	27
Yes	1,601	52	19	29
BMI				
Low	266	50	21	29
Normal	1,121	51	22	27

Table 3-87. Percentage of Mean Water Intake Consumed as Unfiltered and Filtered Tap Water by Pregnant Women (continued)

Variables		Cold Unfiltered Tap Water	Cold Filtered Tap Water	Bottled Water
	N	%	%	%
Overweight	287	53	18	28
Obese	540	56	14	29
Diabetes				
No diabetes	2,209	52	19	28
Regular diabetes	17	69	15	16
Gestational diabetes	54	50	22	27
Nausea during pregnancy				
No	385	54	18	28
Yes	1,893	52	20	28
Pregnancy history				
No prior pregnancy	685	48	21	31
Prior pregnancy with no SAB[b]	1,060	54	18	27
Prior pregnancy with SAB	535	53	20	26
Caffeine				
0 mg/day	577	50	22	27
1–150 mg/day	520	53	17	29
151–300 mg/day	432	52	17	30
>300 mg/day	751	53	19	27
Vitamin use				
No	176	57	8	34
Yes	2,104	52	20	28
Smoking				
Non-smoker	2,151	51	20	28
<10 cigarettes/day	84	60	10	28
≥10 cigarettes/day	45	66	7	22
Alcohol use				
No	2,244	52	19	28
Yes	36	58	19	23
Recreational exercise				
No	1,053	54	14	31
Yes	1,227	51	24	26
Illicit drug use				
No	2,013	51	20	28
Yes	266	56	12	31

[a] LMP = Age of Last Menstrual Period.
[b] SAB = spontaneous abortion.
BMI = body mass index.

Source: Forssen et al. (2007).

Table 3-88. Water Intake at Various Activity Levels (L/hour)[a]

Room Temperature[b] (°F)	Activity Level					
	High (0.15 hp/man)[c]		Medium (0.10 hp/man)[c]		Low (0.05 hp/man)[c]	
	N[d]	Intake	*N*	Intake	*N*	Intake
100	-	-	-	-	15	0.653 (0.75)
95	18	0.540 (0.31)	12	0.345 (0.59)	6	0.50 (0.31)
90	7	0.286 (0.26)	7	0.385 (0.26)	16	0.23 (0.20)
85	7	0.218 (0.36)	16	0.213 (0.20)	-	-
80	16	0.222 (0.14)	-	-	-	-

[a] Data expressed as mean intake with standard deviation in parentheses.
[b] Humidity = 80%; air velocity = 60 ft/minute.
[c] The symbol "hp" refers to horsepower.
[d] Number of subjects with continuous data.
- Data not reported in the source document.

Source: McNall and Schlegel (1968).

Table 3-89. Planning Factors for Individual Tap Water Consumption

Environmental Condition	Recommended Planning Factor (gal/day)[a]	Recommended Planning Factor (L/day)[a,b]
Hot	3.0[c]	11.4
Temperate	1.5[d]	5.7
Cold	2.0[e]	7.6

[a] Based on a mix of activities among the workforce as follows: 15% light work; 65% medium work; 20% heavy work. These factors apply to the conventional battlefield where no nuclear, biological, or chemical weapons are used.
[b] Converted from gal/day to L/day.
[c] This assumes 1 quart/12-hour rest period/man for perspiration losses and 1 quart/day-man for urination plus 6 quarts/12-hours light work/man, 9 quarts/12-hours moderate work/man, and 12 quarts/12-hours heavy work/man.
[d] This assumes 1 quart/12-hour rest period/man for perspiration losses and 1 quart/day/man for urination plus 1 quart/12-hours light work/man, 3 quarts/12-hours moderate work/man, and 6 quarts/12-hours heavy work/man.
[e] This assumes 1 quart/12-hour rest period/man for perspiration losses, 1 quart/day/man for urination, and 2 quarts/day/man for respiration losses plus 1 quart/12-hours light work/man, 3 quarts/12-hours moderate work/man, and 6 quarts/6-hours heavy work/man.

Source: U.S. Army (1983).

Table 3-90. Pool Water Ingestion by Swimmers

Study Group	Number of Participants	Average Water Ingestion Rate (mL/45-minute interval)	Average Water Ingestion Rate (mL/hour)[a]
Children <18 years old	41	37	49
Males <18 years old	20	45	60
Females <18 years old	21	30	43
Adults (>18 years)	12	16	21
Men	4	22	29
Women	8	12	16

[a] Converted from mL/45-minute interval.

Source: Dufour et al. (2006).

Table 3-91. Arithmetic Mean (maximum) Number of Dives per Diver and Volume of Water Ingested (mL/dive)

Divers and Locations	% of Divers	# of Dives	Volume of Water Ingested (mL)
Occupational Divers (*N* = 35)			
Open sea	57	24 (151)	8.7 (25)
Coastal water, USD <1 km	23	3.2 (36)	9.7 (25)
Coastal water, USD >1 km	20	1.8 (16)	8.3 (25)
Coastal water, USD unknown	51	16 (200)	12 (100)
Open sea and coastal combined	-	-	9.8 (100)
Freshwater, USD <1 km	37	8.3 (76)	5.5 (25)
Freshwater, USD >1 km	37	16 (200)	5.5 (25)
Freshwater, no USD	37	16 (200)	4.8 (25)
Freshwater, USD unknown	77	45 (200)	6.0 (25)
All freshwater combined	-	-	5.7 (25)
Sports Divers—ordinary mask (*N* = 482)			
Open sea			
Coastal water	26	2.1 (120)	7.7 (100)
Open sea and coastal combined	78	14 (114)	9.9 (190)
Fresh recreational water	-	-	9.0 (190)
Canals and rivers	85	22 (159)	13 (190)
City canals	11	0.65 (62)	3.4 (100)
Canals, rivers, city canals combined	1.5	0.031 (4)	2.8 (100)
Swimming pools	-	-	3.2 (100)
	65	17 (134)	20 (190)
Sports Divers—full face mask (*N* = 482)			
Open sea			
Coastal water	0.21	0.012 (6)	0.43 (2.8)
Fresh recreational water	1.0	0.10 (34)	1.3 (15)
Canals and rivers	27	0.44 (80)	1.3 (15)
City canals	1.2	0.098 (13)	0.47 (2.8)
All surface water combined	0.41	0.010 (3)	0.31 (2.8)
Swimming pools	-	-	0.81 (25)
	2.3	0.21 (40)	13 (190)

N = Number of divers.
USD = Upstream sewage discharge.

Source: Schijven and de Roda Husman (2006).

Table 3-92. Exposure Parameters for Swimmers in Swimming Pools, Freshwater, and Seawater

Parameter	Adults				Children <15 years	
	Men		Women			
	Mean	95% UCI	Mean	95% UCI	Mean	95% UCI
Swimming Duration (min)						
Swimming Pool	68	180	67	170	81	200
Freshwater	54	200	54	220	79	270
Seawater	45	160	41	180	65	240
Volume Water Swallowed (mL)						
Swimming Pool	34	170	23	110	51	200
Freshwater	27	140	18	86	37	170
Seawater	27	140	18	90	31	140

UCL = Upper confidence interval.

Source: Schets et al. (2011).

Table 3-93. Estimated Water Ingestion During Water Recreation Activities (mL/hr)

Activity	Surface Water Study				Swimming Pool Study			
	N	Median	Mean	UCL	N	Median	Mean	UCL
Limited Contact Scenarios								
Boating	316	2.1	3.7	11.2	0	-	-	-
Canoeing	766				76			
no capsize		2.2	3.8	11.4		2.1	3.6	11.0
with capsize		3.6	6.0	19.9		3.9	6.6	22.4
all activities		2.3	3.9	11.8		2.6	4.4	14.1
Fishing	600	2.0	3.6	10.8	121	2.0	3.5	10.6
Kayaking	801				104			
no capsize		2.2	3.8	11.4		2.1	3.6	10.9
with capsize		2.9	5.0	16.5		4.8	7.9	26.8
all activities		2.3	3.8	11.6		3.1	5.2	17.0
Rowing	222				0			
no capsize		2.3	3.9	11.8		-	-	-
with capsize		2.0	3.5	10.6		-	-	-
all activities		2.3	3.9	11.8		-	-	-
Wading/splashing	0	-	-	-	112	2.2	3.7	1.0
Walking	0	-	-	-	23	2.0	3.5	1.0
Full Contact Scenarios								
Immersion	0	-	-	-	112	3.2	5.1	15.3
Swimming	0	-	-	-	114	6.0	10.0	34.8
TOTAL	2,705				662			

N = Number of participants.
UCL = Upper confidence limit (i.e. mean +1.96 × standard deviation).
\- = No data.

Source: Dorevitch et al. (2011).

4. NON-DIETARY INGESTION FACTORS

4.1. INTRODUCTION

Adults and children have the potential for exposure to toxic substances through non-dietary ingestion pathways other than soil and dust ingestion (e.g., ingesting pesticide residues that have been transferred from treated surfaces to the hands or objects that are mouthed). Adults mouth objects such as cigarettes, pens and pencils, or their hands. Young children mouth objects, surfaces, or their fingers as they explore their environment. Mouthing behavior includes all activities in which objects, including fingers, are touched by the mouth or put into the mouth—except for eating and drinking—and includes licking, sucking, chewing, and biting (Groot et al., 1998). In addition, the sequence of events can be important, such as when a hand-washing occurs relative to contact with soil and hand-to-mouth contact. Videotaped observations of children's mouthing behavior demonstrate the intermittent nature of hand-to-mouth and object-to-mouth behaviors in terms of the number of contacts recorded per unit of time (Ko et al., 2007).

Adult and children's mouthing behavior can potentially result in ingestion of toxic substances (Lepow et al., 1975). Only one study was located that provided data on mouthing frequency or duration for adults, but Cannella et al. (2006) indicated that adults with developmental disabilities frequently exhibit excessive hand-mouthing behavior. In a large non-random sample of children born in Iowa, parents reported non-nutritive sucking behaviors to be very common in infancy, and to continue for a substantial proportion of children up to the 3rd and 4th birthdays (Warren et al., 2000). Hand-to-mouth behavior has been observed in both preterm and full-term infants (Takaya et al., 2003; Blass et al., 1989; Rochat et al., 1988). Infants are born with a sucking reflex for breast-feeding, and within a few months, they begin to use sucking or mouthing as a means to explore their surroundings. Sucking also becomes a means of comfort when a child is tired or upset. In addition, teething normally causes substantial mouthing behavior (i.e., sucking or chewing) to alleviate discomfort in the gums (Groot et al., 1998).

There are three general approaches to gather data on children's mouthing behavior: real-time hand recording, in which trained observers manually record information (Davis et al., 1995); video-transcription, in which trained videographers tape a child's activities and subsequently extract the pertinent data manually or with computer software (Black et al., 2005; Zartarian et al., 1998, 1997a; Zartarian et al., 1997b); and questionnaire, or survey response, techniques (Stanek et al., 1998). With real-time hand recording, observations made by trained professionals—rather than parents—may offer the advantage of consistency in interpreting visible behaviors and may be less subjective than observations made by someone who maintains a caregiving relationship to the child. On the other hand, young children's behavior may be influenced by the presence of unfamiliar people (Davis et al., 1995). Groot et al. (1998) indicated that parent observers perceived that deviating from their usual care giving behavior by observing and recording mouthing behavior appeared to have influenced their children's behavior. With video-transcription methodology, an assumption is made that the presence of the videographer or camera does not influence the child's behavior. This assumption may result in minimal biases introduced when filming newborns, or when the camera and videographer are not visible to the child. However, if the children being studied are older than newborns and can see the camera or videographer, biases may be introduced. Ferguson et al. (2006) described apprehension caused by videotaping as well as situations where a child's awareness of the videotaping crew caused "play-acting" to occur, or parents indicated that the child was behaving differently during the taping session, although children tend to ignore the presence of the camera after some time has passed. Another possible source of measurement error may be introduced when children's movements or positions cause their mouthing not to be captured by the camera. Data transcription errors can bias results in either the negative or positive direction. Finally, measurement error can occur if situations arise in which caregivers are absent during videotaping and researchers must stop videotaping and intervene to prevent risky behaviors (Zartarian et al., 1995). Meanwhile, survey response studies rely on responses to questions about a child's mouthing behavior posed to parents or caregivers. Measurement errors from these studies could occur for a number of different reasons, including language/dialect differences between interviewers and respondents, question wording problems and lack of definitions for terms used in questions, differences in respondents' interpretation of questions, and recall/memory effects.

Some researchers express mouthing behavior as the frequency of occurrence (e.g., contacts per hour or contacts per minute). Others describe the duration of specific mouthing events, expressed in units of seconds or minutes. This chapter does not address issues related to contaminant transfer from thumbs, fingers, or objects or surfaces, into the mouth, and subsequent ingestion. Examples of how to use mouthing frequency and duration data can be found in a U.S. Environmental Protection Agency (U.S. EPA) Office of Pesticide Programs guidance document for conducting residential exposure assessments (U.S. EPA, 2009). This guidance document provides a standard method for estimating potential dose among toddlers from incidental ingestion of pesticide residues from previously treated turf. This scenario assumes that pesticide residues are transferred to the skin of toddlers playing on treated yards and are subsequently ingested as a result of hand-to-mouth transfer. A second scenario assumes that pesticide residues are transferred to a child's toy and are subsequently ingested as a result of object-to-mouth transfer. Neither scenario includes residues ingested as a result of soil ingestion.

The recommendations for mouthing frequency and duration for children only are provided in the next section, along with a summary of the confidence ratings for these recommendations. The recommended values for children are based on key studies identified by the U.S. EPA for this factor. Although some studies in Sections 4.3.1 and 4.4.1 are classified as key, they were not directly used to provide the recommendations. They are included as key because they were used by Xue et al. (2007) or Xue et al. (2010) in meta-analyses, which are the primary sources of the recommendations provided in this chapter for hand-to-mouth and object-to-mouth frequency, respectively. Following the recommendations, key and relevant studies on mouthing frequency (see Section 4.3) and duration (see Section 4.4) are summarized and the methodologies used in the key and relevant studies are described. Information on the prevalence of mouthing behavior is presented in Section 4.5.

4.2. RECOMMENDATIONS

The key studies described in Section 4.3 and Section 4.4 were used to develop recommended values for mouthing frequency and duration, respectively, among children. Only one relevant study was located that provided data on mouthing frequency or duration for adults. The recommended hand-to-mouth frequencies are based on data from Xue et al. (2007). Xue et al. (2007) conducted a secondary analysis of data from several of the studies summarized in this chapter, as well as data from unpublished studies. Xue et al. (2007) provided data for the age groups in U.S. EPA's *Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants* (U.S. EPA, 2005) and categorized the data according to indoor and outdoor contacts. The recommendations for frequency of object-to-mouth contact are based on data from Xue et al. (2010). Xue et al. (2010) conducted a secondary analysis of data from several of the studies summarized in this chapter, as well as data from an unpublished study. Recommendations for duration of object-to-mouth contacts are based on data from Juberg et al. (2001), Greene (2002), and Beamer et al. (2008). Recommendations on duration of object-to-mouth contacts pre-dated the U.S. EPA's (2005) guidance on age groups. For cases in which age groups of children in the key studies did not correspond exactly to U.S. EPA's recommended age groups, the closest age group was used.

Table 4-1 shows recommended mouthing frequencies, expressed in units of contacts per hour, between either any part of the hand (including fingers and thumbs) and the mouth or between an object or surface and the mouth. Recommendations for hand-to-mouth duration are not provided since the algorithm to estimate exposures from this pathway is not time dependent. Table 4-2 presents the confidence ratings for the recommended values. The overall confidence rating is low for both frequency and duration of hand-to-mouth and object-to-mouth contact.

Table 4-1. Summary of Recommended Values for Mouthing Frequency and Duration

Age Group	Hand-to-Mouth Indoor Frequency (contacts/hour) Mean	Hand-to-Mouth Indoor Frequency (contacts/hour) 95th percentile	Hand-to-Mouth Outdoor Frequency (contacts/hour) Mean	Hand-to-Mouth Outdoor Frequency (contacts/hour) 95th percentile	Source
Birth to <1 month	-	-	-	-	Xue et al. (2007)
1 to <3 months	-	-	-	-	
3 to <6 months	28	65	-	-	
6 to <12 months	19	52	15	47	
1 to <2 years	20	63	14	42	
2 to <3 years	13	37	5	20	
3 to <6 years	15	54	9	36	
6 to <11 years	7	21	3	12	
11 to <16 years	-	-	-	-	
16 to <21 years	-	-	-	-	
Object-to-Mouth	Indoor Frequency (contacts/hour) Mean	Indoor Frequency (contacts/hour) 95th percentile	Outdoor Frequency (contacts/hour) Mean	Outdoor Frequency (contacts/hour) 95th percentile	
Birth to <1 month	-	-	-	-	Xue et al. (2010)
1 to <3 months	-	-	-	-	
3 to <6 months	11	32	-	-	
6 to <12 months	20	38	-	-	
1 to <2 years	14	34	8.8	21	
2 to <3 years	9.9	24	8.1	40	
3 to <6 years	10	39	8.3	30	
6 to <11 years	1.1	3.2	1.9	9.1	
11 to <16 years	-	-	-	-	
16 to <21 years	-	-	-	-	
	Mean Duration (minutes/hour)		95th percentile Duration (minutes/hour)		
Birth to <1 month	-		-		Juberg et al. (2001); Greene (2002); Beamer et al. (2008)
1 to <3 months	-		-		
3 to <6 months	11[a]		26[b]		
6 to <12 months	9[c]		19[d]		
1 to <2 years	7[e]		22[e]		
2 to <3 years	10[f]		11[g]		
3 to <6 years	-		-		
6 to <11 years	-		-		
11 to <16 years	-		-		
16 to <21 years	-		-		

[a] Mean calculated from Juberg et al. (2001) (0 to 18 months) and Greene (2002) (3 to 12 months).
[b] Calculated 95th percentile from Greene (2002) (3 to 12 months).
[c] Mean calculated from Juberg et al. (2001) (0 to 18 months), Greene (2002) (3 to 12 months), and Beamer et al. (2008) (6 to 13 months).
[d] Calculated 95th percentile from Greene (2002) (3 to 12 months) and Beamer et al. (2008) (6 to 13 months).
[e] Mean and 95th percentile from Greene (2002) (12 to 24 months).
[f] Mean calculated from Juberg et al. (2001) (19 to 36 months), Greene (2002) (24 to 36 months), and Beamer et al. (2008) (20 to 26 months).
[g] Calculated 95th percentile from Greene (2002) (24 to 36 months) and Beamer et al. (2008) (20 to 26 months).
\- = No data.

Table 4-2. Confidence in Mouthing Frequency and Duration Recommendations

General Assessment Factor	Rationale	Rating
Soundness		Low
Adequacy of Approach	The approaches for data collection and analysis used were adequate for providing estimates of children's mouthing frequencies and durations. Sample sizes were very small relative to the population of interest. Xue et al. (2007) and (2010) meta-analysis of secondary data was considered to be of suitable utility for the purposes for developing recommendations.	
Minimal (or defined) Bias	Bias in either direction likely exists in both frequency and duration estimates; the magnitude of bias is unknown.	
Applicability and Utility		Low
Exposure Factor of Interest	Key studies for older children focused on mouthing behavior while the infant studies were designed to research developmental issues.	
Representativeness	Most key studies were of samples of U.S. children, but, due to the small sample sizes and small number of locations under study, the study subjects may not be representative of the overall U.S. child population.	
Currency	The studies were conducted over a wide range of dates. However, the currency of the data is not expected to affect mouthing behavior recommendations.	
Data Collection Period	Extremely short data collection periods may not represent behaviors over longer time periods.	
Clarity and Completeness		Low
Accessibility	The journal articles are in the public domain, but, in many cases, primary data were unavailable.	
Reproducibility	Data collection methodologies were capable of providing results that were reproducible within a certain range.	
Quality Assurance	Several of the key studies applied and documented quality assurance/quality control measures.	
Variability and Uncertainty		Low
Variability in Population	The key studies characterized inter-individual variability to a limited extent, and they did not characterize intra-individual variability over diurnal or longer term time frames.	
Description of Uncertainty	The study authors typically did not attempt to quantify uncertainties inherent in data collection methodology (such as the influence of observers on behavior), although some described these uncertainties qualitatively. The study authors typically did attempt to quantify uncertainties in data analysis methodologies (if video-transcription methods were used). Uncertainties arising from short data collection periods typically were unaddressed either qualitatively or quantitatively.	
Evaluation and Review		Medium
Peer Review	All key studies appear in peer-review journals.	
Number and Agreement of Studies	Several key studies were available for both frequency and duration, but data were not available for all age groups. The results of studies from different researchers are generally in agreement.	
Overall rating		**Low**

4.3. NON-DIETARY INGESTION—MOUTHING FREQUENCY STUDIES

4.3.1. Key Studies of Mouthing Frequency

4.3.1.1. *Zartarian et al. (1997b)—Quantifying Videotaped Activity Patterns: Video Translation Software and Training Technologies/Zartarian et al. (1997a)—Quantified Dermal Activity Data From a Four-Child Pilot Field Study/Zartarian et al. (1998)—Quantified Mouthing Activity Data From a Four-Child Pilot Field Study*

Zartarian et al. (1998, 1997a; 1997b) conducted a pilot study of the video-transcription methodology to investigate the applicability of using videotaping for gathering information related to children's activities, dermal exposures, and mouthing behaviors. The researchers had conducted studies using the real-time hand recording methodology. These studies demonstrated poor inter-observer reliability and observer fatigue when working for long periods of time. This prompted the investigation into using videotaping with transcription of the children's activities at a point in time after the videotaped observations occurred.

Four Mexican American farm worker children in the Salinas Valley of California each were videotaped with a hand-held video camera during their waking hours, excluding time spent in the bathroom, over one day in September 1993. The boys were 2 years 10 months old and 3 years 9 months old; the girls were 2 years and 5 months old, and 4 years and 2 months old. Time of videotaping was 6.0 hours for the younger girl, 6.6 hours for the older girl, 8.4 hours for the younger boy and 10.1 hours for the older boy. The videotaping gathered information on detailed micro-activity patterns of children to be used to evaluate software for videotaped activities and translation training methods. The researchers reported measures taken to assess inter-observer reliability and several problems with the video-transcription process.

The hourly data showed that non-dietary object mouthing occurred in 30 of the 31 hours of tape time, with one child eating during the hour in which no non-dietary object mouthing occurred. Mean object-to-mouth contacts for the four children were reported to be 11 contacts per hour (median = 9 contacts per hour), with an average per child range of 1 to 29 contacts per hour (Zartarian et al., 1998). Objects mouthed included bedding/towels, clothes, dirt, grass/vegetation, hard surfaces, hard toys, paper/card, plush toy, and skin (Zartarian et al., 1998). Average hand-to-mouth contacts for the four children were 13 contacts per hour [averaging the sum of left hand and right hand-to-mouth contacts and averaging across children, from Zartarian et al. (1997a)], with the average per child ranging from 9 to 19 contacts per hour.

This study's primary purpose was to develop and evaluate the video-transcription methodology; a secondary purpose was collection of mouthing behavior data. The sample of children studied was very small and not likely to be representative of the national population. As with other video-transcription studies, the presence of non-family-member videographers and a video camera may have influenced the children's behavior.

4.3.1.2. *Reed et al. (1999)—Quantification of Children's Hand and Mouthing Activities Through a Videotaping Methodology*

In this study, Reed et al. (1999) used a video-transcription methodology to quantify the frequency and type of children's hand and mouth contacts, as well as a survey response methodology, and compared the videotaped behaviors with parents' perceptions of those behaviors. Twenty children ages 3 to 6 years old selected randomly at a daycare center in New Brunswick, NJ, and 10 children ages 2 to 5 years old at residences in Newark and Jersey City, NJ who were not selected randomly, were studied (sex not specified). For the video-transcription methodology, inter-observer reliability tests were performed during observer training and at four points during the two years of the study. The researchers compared the results of videotaping the ten children in the residences with their parents' reports of the children's daily activities. Mouthing behaviors studied included hand-to-mouth and hand bringing object-to-mouth.

Table 4-3 presents the video-transcription mouthing contact frequency results. The authors analyzed parents' responses on frequencies of their children's mouthing behaviors and compared those responses with the children's videotaped behaviors, which revealed certain discrepancies: Parents' reported hand-to-mouth contact of "almost never" corresponded to overall somewhat lower videotaped hand-to-mouth frequencies than those of children whose parents reported "sometimes," but there was little correspondence between parents' reports of object-to-mouth frequency and videotaped behavior.

The advantages of this study were that it compared the results of video-transcription with the survey response methodology results and that it described quality assurance steps taken to assure reliability of transcribed videotape data. However, only a small number of children were studied, some were not selected for observation randomly, and the sample of children studied may not be representative of either the locations studied or the national population. Because of the children's ages, the presence of unfamiliar persons following the children with a video camera may influence the video-transcription results. The parents' survey responses also may be influenced by recall/memory effects and other limitations of survey methodologies.

4.3.1.3. *Freeman et al. (2001)—Quantitative Analysis of Children's Micro-Activity Patterns: The Minnesota Children's Pesticide Exposure Study*

Freeman et al. (2001) conducted a survey response and video-transcription study of some of the respondents in a phased study of children's pesticide exposures in the summer and early fall of 1997. A probability-based sample of 168 families with children ages 3 to <14 years old in urban (Minneapolis/St. Paul) and non-urban (Rice and Goodhue Counties) areas of Minnesota answered questions about children's mouthing of paint chips, food-eating without utensils, eating of food dropped on the floor, mouthing of non-food items, and mouthing of thumbs and fingers. For the survey response portion of the study, parents provided the responses for children ages 3 and 4 years and collaborated with or assisted older children with their responses. Of the 168 families responding to the survey, 102 were available, selected, and agreed to measurements of pesticide exposure. Of these 102 families, 19 agreed to videotaping of the study children's activities for a period of 4 consecutive hours.

Based on the survey responses for 168 children, the 3-year olds had significantly more positive responses for all reported behavior compared to the other age groups. The authors stated that they did not know whether parent reporting of 3-year olds' behavior influenced the responses given. Table 4-4 shows the percentage of children, grouped by age, who were reported to exhibit non-food related mouthing behaviors. Table 4-5 presents the mean and median number of mouthing contacts by age for the 19 videotaped children. Among the four age categories of these children, object-to-mouth activities were significantly greater for the 3- and 4-year olds than any other age group, with a median of 3 and a mean of 6 contacts per hour ($p = 0.002$, Kruskal Wallis test comparison across four age groups). Hand-to-mouth contacts had a median of 3.5 and mean of 4 contacts per hour for the three 3- and 4-year olds observed, median of 2.5 and mean of 8 contacts per hour for the seven 5- and 6-year olds observed, median of 3 and mean of 5 contacts per hour for the four 7- and 8-year olds observed, and median of 2 and mean of 4 for the five 10-, 11-, and 12-year olds observed. Sex differences were observed for some of the activities, with boys spending significantly more time outdoors than girls. Hand-to-mouth and object-to-mouth activities were less frequent outdoors than indoors for both boys and girls.

For the 19 children in the video-transcription portion of the study, inter-observer reliability checks and quality control checks were performed on randomly sampled tapes. For four children's tapes, comparison of the manual video-transcription with a computerized transcription method (Zartarian et al., 1995) also was performed; no significant differences were found in the frequency of events recorded using the two techniques. The frequency of six behaviors (hand-to-mouth, hand-to-object, object-to-mouth, hand-to-smooth surface, hand-to-textured surface, and hand-to-clothing) was recorded. The amount of time each child spent indoors, outdoors, and in contact with soil or grass, as well as whether the child was barefoot was also recorded. For the four children whose tapes were analyzed with the computerized transcription method, which calculates event durations, the authors stated that most hand-to-mouth and object-to-mouth activities were observed during periods of lower physical activity, such as television viewing.

An advantage to this study is that it included results from two separate methodologies, and included quality assurance steps taken to assure reliability of transcribed videotape data. However, the children in this study may not be representative of all children in the United States. Variation in who provided the survey responses (sometimes parents only, sometimes children with parents) may have influenced the responses given. Children studied using the video-transcription methodology were not chosen randomly from the survey response group. The presence of unfamiliar persons following the children with a video camera may have influenced the video-transcription methodology results.

4.3.1.4. *Tulve et al. (2002)—Frequency of Mouthing Behavior in Young Children*

Tulve et al. (2002) coded the unpublished Davis et al. (1995) data for location (indoor and outdoor) and activity type (quiet or active) and analyzed the subset of the data that consisted of indoor mouthing behavior during quiet activity (72 children, ranging in age from 11 to 60 months). A total of one hundred eighty-six 15-minute observation periods were included in the study, with the number of observation periods per child ranging from 1 to 6. Tulve et al. (2002) used the Davis et al. (1995) data from which the children were selected randomly based on date of birth through a combination of birth certificate records and random digit dialing of residential telephone numbers.

Results of the data analyses indicated that there was no association between mouthing frequency and sex, but a clear association between mouthing frequency and age was observed. The analysis indicated that children ≤24 months had the highest frequency of mouthing behavior (81 events/hour) and that children >24 months had the lowest (42 events/hour) (see Table 4-6). Both groups of children were observed to mouth toys and hands more frequently than household surfaces or body parts other than hands.

An advantage of this study is that the randomized design may mean that the children studied were relatively representative of young children living in the study area, although they may not be representative of the U.S. population. Due to the ages of the children studied, the observers' use of headphones and manual recording of mouthing behavior on observation sheets may have influenced the children's behavior.

4.3.1.5. *AuYeung et al. (2004)—Young Children's Mouthing Behavior: An Observational Study via Videotaping in a Primarily Outdoor Residential Setting*

AuYeung et al. (2004) used a video-transcription methodology to study a group of 38 children (20 females and 18 males; ages 1 to 6 years), 37 of whom were selected randomly via a telephone screening survey of a 300 to 400 square mile portion of the San Francisco, CA peninsula, along with one child selected by convenience because of time constraints. Families who lived in a residence with a lawn and whose annual income was >$35,000 were asked to participate. Videotaping took place between August 1998 and May 1999 for approximately two hours per child. Videotaping by one researcher was supplemented with field notes taken by a second researcher who also was present during taping. Most of the videotaping took place during outdoor play, however, data were included for several children (one child <2 years old and eight children >2 years old) who had more than 15 minutes of indoor play during their videotaping sessions.

The videotapes were translated into American Standard Code for Information Interchange (ASCII) computer files using Virtual Timing Device™ software described in Zartarian et al. (1997b). Both frequency and duration (see Section 4.4.2.5 of this chapter) were analyzed. Between 5% and 10% of the data files translated were randomly chosen for quality control checks for inter-observer agreement. Ferguson et al. (2006) described quality control aspects of the study in detail.

For analysis, the mouthing contacts were divided into indoor and outdoor locations and 16 object/surface categories. Mouthing frequency was analyzed by age and sex separately and in combination. Mouthing contacts were defined as contact with the lips, inside of the mouth, and/or the tongue; dietary contacts were ignored. Table 4-7 shows mouthing frequencies for indoor locations. For the one child observed that was ≤24 months of age, the total mouthing frequency was 84.8 contacts/hour; for children >24 months, the median indoor mouthing frequency was 19.5 contacts/hour. Outdoor median mouthing frequencies (see Table 4-8) were very similar for children ≤24 months of age (13.9 contacts/hour) and >24 months (14.6 contacts/hour).

Non-parametric tests, such as the Wilcoxon rank sum test, were used for the data analyses. Both age and sex were found to be associated with differences in mouthing behavior. Girls had significantly higher frequencies of mouthing contacts with the hands and non-dietary objects than boys ($p = 0.01$ and $p = 0.008$, respectively).

This study provides distributions of outdoor mouthing frequencies with a variety of objects and surfaces. Although indoor mouthing data also were included in this study, the results were based on a small number of children ($N = 9$) and a limited amount of indoor play. The sample of children may be representative of certain socioeconomic strata in the study area, but it is not likely to be representative of the national population. Because of the children's ages, the presence of unfamiliar persons following the children with a video camera may have influenced the video-transcription methodology results.

4.3.1.6. *Black et al. (2005)—Children's Mouthing and Food-Handling Behavior in an Agricultural Community on the U.S./Mexico Border*

Black et al. (2005) studied mouthing behavior of children in a Mexican-American community along the Rio Grande River in Texas, during the spring and summer of 2000, using a survey response and a video-transcription methodology. A companion study of this community (Shalat et al., 2003) identified 870 occupied households during the April 2000 U.S. Census and contacted 643 of these via in-person interview to determine the presence of children under the age of 3 years. Of the 643 contacted, 91 had at least one child under the age of 3 years (Shalat et al., 2003). Of these 91 households, the mouthing and food-handling behavior of 52 children (26 boys and 26 girls) from 29 homes was videotaped, and the children's parents answered questions about children's hygiene, mouthing and food-handling activities (Black et al., 2005). The study was of children ages 7 to 53 months, grouped into four age categories: infants (7 to 12 months), 1-year olds (13 to 24 months), 2-year olds (25 to 36 months), and preschoolers (37 to 53 months).

The survey asked questions about children's ages, sexes, reported hand-washing, mouthing and food-handling behavior (N = 52), and activities (N = 49). Parental reports of thumb/finger placement in the mouth showed decreases with age. The researchers attempted to videotape each child for 4 hours. The children were followed by the videographers through the house and yard, except for times when they were napping or using the bathroom. Virtual Timing Device™ software, mentioned earlier, was used to analyze the videotapes.

Based on the results of videotaping, most of the children (49 of 52) spent the majority of their time indoors. Of the 39 children who spent time both indoors and outdoors, all three behaviors (hand-to-mouth, object-to-mouth and food handling) were more frequent and longer while the child was indoors. Hand-to-mouth activity was recorded during videotaping for all but one child, a 30 month old girl.

For the four age groups, the mean hourly hand-to-mouth frequency ranged from 11.9 (2-year olds) to 22.1 (preschoolers), and the mean hourly object-to-mouth frequency ranged from 7.8 (2-year olds) to 24.4 (infants). No significant linear trends were seen with age or sex for hand-to-mouth hourly frequency. A significant linear trend was observed for hourly object-to-mouth frequency, which decreased as age increased (adjusted R^2 = 0.179; p = 0.003). Table 4-9 shows the results of this study.

Because parental survey reports were not strongly correlated with videotaped hand or object mouthing, the authors suggested that future research might include alternative methods of asking about mouthing behavior to improve the correlation of questionnaire data with videotaped observations.

One advantage of this study is that it compared survey responses with videotaped information on mouthing behavior. A limitation is that the sample was fairly small and was from a limited area (mid-Rio Grande Valley) and is not likely to be representative of the national population. Because of the children's ages, the presence of unfamiliar persons following the children with a video camera may have influenced the video-transcription methodology results.

4.3.1.7. *Xue et al. (2007)—A Meta-Analysis of Children's Hand-to-Mouth Frequency Data for Estimating Non-Dietary Ingestion Exposure*

Xue et al. (2007) gathered hand-to-mouth frequency data from nine available studies representing 429 subjects and more than 2,000 hours of behavior observation (Beamer et al., 2008; Black et al., 2005; Hore, 2003; Greene, 2002; Tulve et al., 2002; Freeman et al., 2001; Leckie et al., 2000; Reed et al., 1999; Zartarian et al., 1998). Two of these studies [i.e., Leckie et al. (2000); Hore (2003)] are unpublished data sets and are not summarized in this chapter. The remaining seven studies are summarized elsewhere in this chapter. Xue et al. (2007) conducted a meta-analysis to study differences in hand-to-mouth behavior. The purpose of the analysis was to

1. examine differences across studies by age [using the new U.S. EPA recommended age groupings (U.S. EPA, 2005)], sex, and indoor/outdoor location;
2. fit variability distributions to the available hand-to-mouth frequency data for use in one-dimensional Monte Carlo exposure assessments;
3. fit uncertainty distributions to the available hand-to-mouth frequency data for use in two-dimensional Monte Carlo exposure assessments; and
4. assess hand-to-mouth frequency data needs using the new U.S. EPA recommended age groupings (U.S. EPA, 2005).

The data were sorted into age groupings. Visual inspection of the data and statistical methods (i.e., method of moments and maximum likelihood estimation) were used, and goodness-of-fit tests were applied to verify the selection among lognormal, Weibull, and normal distributions (Xue et al., 2007). Analyses to study inter- and intra-individual variability of indoor and outdoor hand-to-mouth frequency were conducted. It was found that age and location (indoor vs. outdoor) were important factors contributing to hand-to-mouth frequency, but study and sex were not (Xue et al., 2007). Distributions of hand-to-mouth frequencies were developed for both indoor and outdoor activities. Table 4-10 presents distributions for indoor settings while Table 4-11 presents distributions for outdoor settings. Hand-to-mouth frequencies decreased for both indoor and outdoor activity as age increased, and they were higher indoors than outdoors for all age groups (Xue et al., 2007).

A strength of this study is that it is the first effort to fit hand-to-mouth distributions of children in different locations while using U.S. EPA's recommended age groups. Limitations of the studies used in this meta-analysis apply to the results from the meta-analysis as well; the uncertainty analysis in this study does not account for uncertainties arising out of differences in approaches used in the various studies used in the meta-analysis.

4.3.1.8. *Beamer et al. (2008)—Quantified Activity Pattern Data From 6 to 27-Month-Old Farm Worker Children for Use in Exposure Assessment*

Beamer et al. (2008) conducted a follow-up to the pilot study performed by Zartarian et al. (1998, 1997a; 1997b), described in Sections 4.3.1.1 and 4.4.2.2. For this study, a convenience sample of 23 children residing in the farm worker community of Salinas Valley, CA, was enrolled. Participants were 6- to 13-month-old infants or 20- to 26-month-old toddlers. Two researchers videotaped each child's activities for a minimum of 4 hours and kept a detailed written log of locations visited and objects and surfaces contacted by the child. A questionnaire was administered to an adult in the household to acquire demographic data, housing and cleaning characteristics, eating patterns, and other information pertinent to the child's potential pesticide exposure.

Table 4-12 presents the distribution of object/surface contact frequency for infants and toddlers in events/hour. The mean hand-to-mouth frequency was 18.4 events/hour. The mean mouthing frequency of non-dietary objects was 29.2 events/hour. Table 4-13 presents the distributions for the mouthing frequency and duration of non-dietary objects, and it highlights the differences between infants and toddlers. Toddlers had higher mouthing frequencies with non-dietary items associated with pica (i.e., paper) while infants had higher mouthing frequencies with other non-dietary objects. In addition, boys had higher mouthing frequencies than girls. The advantage of this study is that it included both infants and toddlers. Differences between the two age groups, as well as sex differences, could be observed. As with other video-transcription studies, the presence of non-family-member videographers and a video camera may have influenced the children's behavior.

4.3.1.9. *Xue et al. (2010)—A Meta-Analysis of Children's Object-to-Mouth Frequency Data for Estimating Non-Dietary Ingestion Exposure*

Xue et al. (2010) gathered object-to-mouth frequency data from 7 available studies representing 438 subjects and approximately 1,500 hours of behavior observation. The studies used in this analysis included six published studies that were also individually summarized in this chapter (Beamer et al., 2008; AuYeung et al., 2004; Greene, 2002; Tulve et al., 2002; Freeman et al., 2001; Reed et al., 1999) as well as one unpublished data set (Hore, 2003). These data were used to conduct a meta-analysis to study differences in object-to-mouth behavior. The purpose of the analysis was to

1. "examine differences across studies by age [using the new U.S. EPA recommended age groupings (U.S. EPA, 2005)], sex, and indoor/outdoor location;
2. fit variability distributions to the available object to-mouth frequency data for use in one dimensional Monte Carlo exposure assessments;
3. fit uncertainty distributions to the available object-to-mouth frequency data for use in two dimensional Monte Carlo exposure assessments; and
4. assess object-to-mouth frequency data needs using the new U.S. EPA recommended age groupings (U.S. EPA, 2005)."

The data were sorted into age groupings. Visual inspection of the data and statistical methods (i.e., method of moments and maximum likelihood estimation) were used, and goodness-of-fit tests were applied to verify the selection among lognormal, Weibull, and normal distributions (Xue et al., 2010). Analyses to study inter- and intra-individual variability of indoor and outdoor object-to-mouth frequency were conducted. It was found that age, location (indoor vs. outdoor), and study were important factors contributing to object-to-mouth frequency, but study and sex were not (Xue et al., 2010). Distributions of object-to-mouth frequencies were developed for both indoor and outdoor activities. Table 4-14 presents distributions for indoor settings while Table 4-15 presents distributions for outdoor settings. Object-to-mouth frequencies decreased for both indoor and outdoor activity as age increased (i.e., after age 6 to <12 months for indoor activity; and after 3 to <6 years for outdoor activity), and were higher indoors than outdoors for all age groups (Xue et al., 2010).

A strength of this study is that it is the first effort to fit object-to-mouth distributions of children in different locations while using U.S. EPA's recommended age groups. Limitations of the studies used in this meta-analysis apply to the results from the meta-analysis as well; the uncertainty analysis in this study does not account for uncertainties arising out of differences in approaches used in the various studies used in the meta-analysis.

4.3.2. Relevant Studies of Mouthing Frequency

4.3.2.1. *Davis et al. (1995)—Soil Ingestion in Children With Pica: Final Report*

In 1992, under a Cooperative Agreement with U.S. EPA, the Fred Hutchinson Cancer Research Center conducted a survey response and real-time hand recording study of mouthing behavior data. The study included 92 children (46 males, 46 females) ranging in age from 12 months to <60 months, from Richland, Kennewick, and Pasco, WA. The children were selected randomly based on date of birth through a combination of birth certificate records and random digit dialing of residential telephone numbers. For each child, data were collected in one 7-day period during January to April, 1992. Eligibility included residence within the city limits, residence duration >1 month, and at least one parent or guardian who spoke English. Most of the adults who responded to the survey reported their marital status as being married (90%), their race as Caucasian (89%), their household income in the >$30,000 range (56%), or their housing status as single-family home occupants (69%).

The survey asked questions about thumb-sucking and frequency questions about pacifier use, placing fingers, hands and feet in the mouth, and mouthing of furniture, railings, window sills, floor, dirt, sand, grass, rocks, mud, clothes, toys, crayons, pens, and other items. Table 4-16 shows the survey responses for the 92 study children. For most of the children in the study, the mouthing behavior real-time hand recording data were collected simultaneously by parents and by trained observers who described and quantified the mouthing behavior of the children in their home environment. The observers recorded mouth and tongue contacts with hands, other body parts, natural objects, surfaces, and toys every 15 seconds during 15-minute observation periods spread over 4 days. Parents and trained observers wore headphones that indicated elapsed time (Davis et al., 1995). If all attempted observation periods were successful, each child would have a total of sixteen 15-minute observation periods with sixty 15-second intervals per 15-minute observation period, or nine hundred sixty 15-second intervals in all. The number of successful intervals of observation ranged from 0 to 840 per child. Comparisons of the inter-observer reliability between the trained observers and parents showed

> "a high degree of correlation between the overall degree of both mouth and tongue activity recorded by parents and observers. For total mouth activity, there was a significant correlation between the rankings obtained according to parents and observers, and parents were able to identify the same individuals as observers as being most and least oral in 60% of the cases" (Davis et al., 1995).

One advantage of this study is the simultaneous observations by both, parents and trained observers, that allow comparisons regarding the consistency of the recorded observations. The random nature in which the population was selected may provide a representative population of the study area, within certain limitations, but not of the national population. In addition, this study was considered relevant because the data were not analyzed for deriving estimates of mouthing contact. These data were analyzed by Tulve et al. (2002) (see Section 4.3.1.4). Simultaneous collection of food, medication, fecal, and urine samples that occurred as part of the overall study (not described in this summary) may have contributed a degree of deviation from normal routines within the households during the 7 days of data collection and may have influenced children's usual behaviors. Wearing of headphones by parents and trained observers during mouthing observations, presence of non-family-member observers, and parents' roles as observers as well as caregivers also may have influenced the results; the authors state "Having the child play naturally while being observed was challenging. Usually the first day of observation was the most difficult in this respect, and by the third or fourth day of observation the child generally paid little attention to the observers."

4.3.2.2. *Lew and Butterworth (1997)—The Development of Hand-Mouth Coordination in 2- to 5-Month-Old Infants: Similarities With Reaching and Grasping*

Lew and Butterworth (1997) studied 14 infants (10 males, 4 females; mostly first-borns) in Stirling, United Kingdom, in 1990 using a video-transcription methodology. Attempts were made to study each infant within 1 week of the infant's 2-, 3-, 4-, and 5-month birthdays. After becoming accustomed to the testing laboratory, and with their mothers present, infants were placed in semi-reclining seats and filmed during an experimental protocol in which researchers placed various objects into the infants' hands. Infants were observed for two baseline periods of 2 minutes each. The researchers coded all contacts to the face and mouth that occurred during baseline periods (prior to and after the object handling period) as well as contacts occurring during the object handling period. Hand-to-mouth contacts included contacts that landed directly in or on the mouth as well as those in which the hand landed on the face first and then moved to the mouth. The researchers assessed inter-observer agreement using a rater not involved with the study, for a random proportion (approximately 10%) of the movements documented during the object handling period, and reported inter-observer agreement of 0.90 using Cohen's kappa for the location of contacts. The frequency of contacts ranged between zero and one contact per minute.

The advantages of this study were that use of video cameras could be expected to have minimal effect on infant behavior for infants of these ages, and the researchers performed tests of inter-observer reliability. A disadvantage is that the study included baseline observation periods of only 2 minutes' duration, during which spontaneous hand-to-mouth movements could be observed. The extent to which these infants' behavior is representative of other infants of these ages is unknown.

4.3.2.3. *Tudella et al. (2000)—The Effect of Oral-Gustatory, Tactile-Bucal, and Tactile-Manual Stimulation on the Behavior of the Hands in Newborns*

Tudella et al. (2000) studied the frequency of hand-to-mouth contact, as well as other behaviors, in 24 full-term Brazilian newborns (10 to 14 days old) using a video-transcription methodology. Infants were in an alert state, in their homes in silent and previously heated rooms in a supine position and had been fed between 1 and 1 1/2 hours before testing. Infants were studied for a 4-minute baseline period without stimuli before experimental stimuli were administered. Results from the four-minute baseline period, without stimuli, indicated that the mean frequency of hand-to-mouth contact (defined as right hand or left hand touching the lips or entering the buccal cavity, either with or without rhythmic jaw movements) was almost 3 right hand contacts and slightly more than 1.5 left hand contacts, for a total hand-to-mouth contact frequency of about 4 contacts in the 4-minute period. The researchers performed inter-observer reliability tests on the videotape data and reported an inter-coder Index of Concordance of 93%.

The advantages of this study were that use of video cameras could be expected to have virtually no effect on newborns' behavior, and inter-observer reliability tests were performed. However, the study data may not represent newborn hand-to-mouth contact during non-alert periods such as sleep. The extent to which these infants' behavior is representative of other full-term 10- to 14-day-old infants' behavior is unknown.

4.3.2.4. *Ko et al. (2007)—Relationships of Video Assessments of Touching and Mouthing Behaviors During Outdoor Play in Urban Residential Yards to Parental Perceptions of Child Behaviors and Blood Lead Levels*

Ko et al. (2007) compared parent survey responses with results from a video-transcription study of children's mouthing behavior in outdoor settings, as part of a study of relationships between children's mouthing behavior and other variables with blood lead levels. A convenience sample of 37 children (51% males, 49% females) 14 to 69 months old was recruited via an urban health center and direct contacts in the surrounding area, apparently in Chicago, IL. Participating children were primarily Hispanic (89%). The mouth area was defined as within 1 inch of the mouth, including the lips. Items passing beyond the lips were defined as in the mouth. Placement of an object or food item in the mouth along with part of the hand was counted as both hand and food or hand and object in mouth. Mouthing behaviors included hand-to-mouth area both with and without food, hand-in-mouth with or without food, and object-in-mouth including food, drinks, toys, or other objects.

Survey responses for the 37 children who also were videotaped included parents reporting children's inserting hand, toys, or objects in mouth when playing outside, and inserting dirt, stones, or sticks in mouth. Video-transcription results of outdoor play for these 37 children indicated 0 to 27 hand-in-mouth and 3 to 69 object-in-mouth touches per hour for the

13 children reported to frequently insert hand, toys, or objects in mouth when playing outside; 0 to 67 hand-in-mouth, and 7 to 40 object-in-mouth touches per hour for the 10 children reported to "sometimes" perform this behavior; 0 to 30 hand-in-mouth and 0 to 125 object in mouth touches per hour for the 12 children reported to "hardly ever" perform this behavior, and 1 to 8 hand-in-mouth and 3 to 6 object-in-mouth touches per hour for the 2 children reported to "never" perform this behavior.

Videotaping was attempted for 2 hours per child over two or more play sessions, with videographers trying to avoid interacting with the children. Children played with their usual toys and partners, and no instructions were given to parents regarding their supervision of the children's play. The authors stated that during some portion of the videotape time, children's hands and mouths were out of camera view. Videotape transcription was performed manually, according to a modified version of the protocol used in the Reed et al. (1999) study. Inter-observer reliability between three video-transcribers was checked with seven 30-minute video segments.

One strength of this study is its comparison of survey responses with results from the video-transcription methodology. A limitation is that the non-randomly selected sample of children studied is unlikely to be representative of the national population. Comparing results from this study with results from other video-transcription studies may be problematic because of inclusion of food handling with hand-to-mouth and object-to-mouth frequency counts. Due to the children's ages, their behavior may have differed from normal patterns because of the presence of strangers who videotaped them.

4.3.2.5. *Nicas and Best (2008)—A Study Quantifying the Hand-to-Face Contact Rate and Its Potential Application to Predicting Respiratory Tract Infection*

Nicas and Best (2008) conducted an observational study on adults (five women and five men; ages not specified), in which individuals were videotaped while performing office-type work for a 3-hour period. The videotapes were viewed by the investigators, who counted the number of hand-to-face touches the subjects made while they worked on a laptop computer, read, or wrote. Following the observations, the sample mean and standard deviation were computed for the number of times each subject touched his or her eyes, nostrils, and lips. For the three combinations of touch frequencies (i.e., lips-eyes, lips-nostrils, eyes-nostrils), Spearman rank correlation coefficients were computed and tests of the hypothesis that the rank correlation coefficients exceeded zero were performed.

Table 4-17 shows the frequency of hand-to-face contacts with the eyes, nostrils, and lips of the subjects, and the sum of these counts. There was considerable inter-individual variability among the subjects. During the 3-hour continuous study period, the total number of hand contacts with the eyes, lips and nostrils ranged from 3 to 104 for individual subjects, with a mean of 47. The mean per hour contact rate was 15.7. There was a positive correlation between the number of hand contacts with lips and eyes and with lips and nostrils (subjects who touched their lips frequently also touched their eyes and nostrils frequently). The Spearman rank correlation coefficients for contacts between different facial targets were 0.76 for the lips and eyes; 0.66 for the lips and nostrils, and 0.44 for the eyes and nostrils.

The study's primary purpose was to quantify hand-to-face contacts in order to determine the application of this contact rate in predicting respiratory tract infection. The authors developed an algebraic model for estimating the dose of pathogens transferred to target facial membranes during a defined exposure period. The advantage of this study is that it determined the frequency of hand-to-face contacts for adults. A limitation of the study is that there were very few subjects (five women and five men) who may not have been representative of the U.S. population. In addition, as with other video-transcription studies, the presence of videographers and a video camera may have influenced the subjects' behaviors.

4.4. NON-DIETARY INGESTION—MOUTHING DURATION STUDIES

4.4.1. Key Mouthing Duration Studies

4.4.1.1. *Juberg et al. (2001)—An Observational Study of Object Mouthing Behavior by Young Children*

Juberg et al. (2001) studied 385 children ages 0 to 36 months in western New York State, with parents collecting real-time hand-recording mouthing behavior data, primarily in the children's own home environments. The study consisted of an initial pilot study conducted in February 1998, a second phase conducted in April 1998, and a third phase conducted at an unspecified later time. The study's sample was drawn from families identified in a child play research center database or whose children attended a child care facility in the same general area; some geographic variation within the local area was obtained by selecting families with different zip codes in the different study phases. The pilot phase had 30 children who participated out of 150 surveys distributed; the second phase had 187 children out of approximately 300 surveys distributed, and the third phase had 168 participants out of 300 surveys distributed.

Parents were asked to observe their child's mouthing of objects only; hand-to-mouth behavior was not included. Data were collected on a single day (pilot and second phases) or 5 days (third phase); parents recorded the insertion of objects into the mouth by noting the "time in" and "time out" and the researchers summed the recorded data to tabulate total times spent mouthing the various objects during the days of observation. Thus, the study data were presented as minutes per day of object mouthing time. Mouthed items were classified as pacifiers, teethers, plastic toys, or other objects.

Table 4-18 shows the results of the combined pilot and second phase data. For both age groups, mouthing time for pacifiers greatly exceeded mouthing time for non-pacifiers, with the difference more acute for the older age group than for the younger age group. Histograms of the observed data show a peak in the low end of the distribution (0 to 100 minutes per day) and a rapid decline at longer durations.

A third phase of the study focused on children between the ages of 3 and 18 months and included only non-pacifier objects. Subjects were observed for 5 non-consecutive days over a 2-month period. A total of 168 participants returned surveys for at least one day, providing a total of 793 person-days of data. The data yielded a mean non-pacifier object mouthing duration of 36 minutes per day; the mean was the same when calculated on the basis of 793 person-days of data as on the basis of 168 daily average mouthing times.

One advantage of this study is the large sample size (385 children); however, the children apparently were not selected randomly, although some effort was made to obtain local geographic variation among study participants. There is no description of the socioeconomic status or racial and ethnic identities of the study participants. The authors do not describe the methodology parents used to record mouthing event durations (e.g., using stopwatches, analog or digital clocks, or guesses). The authors stated that using mouthing event duration units of minutes rather than seconds may have yielded observations rounded to the nearest minute.

4.4.1.2. *Greene (2002)—A Mouthing Observation Study of Children Under Six Years of Age*

The U.S. Consumer Product Safety Commission conducted a survey response and real-time hand recording study between December 1999 and February 2001 to quantify the cumulative time per day that young children spend awake, not eating, and mouthing objects. "Mouthing" was defined as children sucking, chewing, or otherwise putting an object on their lips or into their mouth. Participants were recruited via a random digit dialing telephone survey in urban and nearby rural areas of Houston, TX and Chicago, IL. Of the 115,289 households surveyed, 1,745 households had a child under the age of 6 years and were willing to participate. In the initial phase of the study, 491 children ages 3 to 81 months participated. Parents were instructed to use watches with second hands or to count seconds to estimate mouthing event durations. Parents also were to record mouthing frequency and types of objects mouthed. Parents collected data in four separate, non-consecutive 15-minute observation periods. Initially, parents were called back by the researchers and asked to provide their data over the telephone. Of the 491 children, 43 children (8.8%) had at least one 15-minute observation period with mouthing event durations recorded as exceeding 15 minutes. Due to this data quality problem, the researchers excluded the parent observation data from further analysis.

In a second phase, trained observers used stopwatches to record the mouthing behaviors and mouthing event durations of the subset of 109 of these children ages 3 to 36 months and an additional 60 children (total in second phase, 169), on 2 hours of each of 2 days. The observations were done at different times of the day at the child's home and/or child care facility. Table 4-19 shows the prevalence of observed mouthing among the 169 children in the second phase. All children were observed to mouth during the 4 hours of observation time; 99% mouthed parts of their anatomy. Pacifiers were mouthed by 27% in an age-declining pattern ranging from 47% of children less than 12 months old to 10% of the 2- to <3-year olds.

Table 4-20 provides the average mouthing time by object category and age in minutes per hour. The average mouthing time for all objects ranged from 5.3 to 10.5 minutes per hour, with the highest mouthing time corresponding to children <1 year of age and the lowest to the 2 to <3 years of age category. Among the objects mouthed, pacifiers represented about one third of the total mouthing time, with 3.4 minutes per hour for the youngest children, 2.6 minutes per hour for the children between 1 and 2 years and 1.8 minutes per hour for children 2 to <3 years old. The next largest single item category was anatomy. In this category, children under 1 year of age spent 2.4 minutes per hour mouthing fingers and thumbs; this behavior declined with age to 1.2 minutes per hour for children 2 to <3 years old.

Of the 169 children in the second phase, data were usable on the time awake and not eating (or "exposure time") for only 109; data for the remaining 60 children were missing. Thus, in order to develop extrapolated estimates of daily mouthing time for the 109 children, from the 2 hours of observation per day for two days, the researchers developed a statistical model that accounted for the children's demographic characteristics, that estimated exposure times for the 60 children with missing data, and then computed statistics for the extrapolated daily mouthing times for all 169 children, using a "bootstrap" procedure. Using this method, the estimated mean daily mouthing time of objects other than pacifiers ranged from 37 minutes/day to 70 minutes/day with the lowest number corresponding to the 2 to <3-year-old children and the largest number corresponding to the 3 to <12-month-old children.

The 551 child participants were 55% males, 45% females. The study's sample was drawn in an attempt to duplicate the overall U.S. demographic characteristics with respect to race, ethnicity, socioeconomic status and urban/suburban/rural settings. The sample families' reported annual incomes were generally higher than those of the overall U.S. population.

This study's strength was that it consisted of a randomly selected sample of children from both urban and non-urban areas in two different geographic areas within the United States. However, the observers' presence and use of a stopwatch to time mouthing durations may have affected the children's behavior.

4.4.1.3. *Beamer et al. (2008)—Quantified Activity Pattern Data From 6- to 27-Month-Old Farm Worker Children for Use in Exposure Assessment*

Beamer et al. (2008) conducted a follow-up to the pilot study performed by Zartarian et al. (1998, 1997a; 1997b), described in Sections 4.3.1.1 and 4.4.2.2. For this study, a convenience sample of 23 children residing in the farm worker community of Salinas Valley, CA was enrolled. Participants were 6- to 13-month-old infants or 20- to 26-month-old toddlers. Two researchers videotaped each child's activities for a minimum of 4 hours, and kept a detailed written log of locations visited and objects and surfaces contacted by the child. A questionnaire was administered to an adult in the household to acquire demographic data, housing and cleaning characteristics, eating patterns, and other information pertinent to the child's potential pesticide exposure.

Table 4-21 presents the object/surface hourly contact duration in minutes/hour. The mean hourly mouthing duration for hands and non-dietary objects was 1.4 and 3.5 minutes/hour, respectively. Infants had higher hourly mouthing duration with toys and all non-dietary objects than toddlers. Girls had higher contact durations than boys.

The advantage of this study is that it included both infants and toddlers. Differences between the two age groups, as well as sex differences, could be observed. As with other video-transcription studies, the presence of non-family-member videographers and a video camera may have influenced the children's behavior.

4.4.2. Relevant Mouthing Duration Studies

4.4.2.1. *Barr et al. (1994)—Effects of Intra-Oral Sucrose on Crying, Mouthing, and Hand-Mouth Contact in Newborn and Six-Week-Old Infants*

Barr et al. (1994) studied hand-to-mouth contact, as well as other behaviors, in 15 newborn (eight males, seven females) and fifteen 5- to 7-week old (eight males, seven females) full-term Canadian infants using a video-transcription methodology. The newborns were 2- to 3-days old, were in a quiet, temperature-controlled room at the hospital, were in a supine position and had been fed between 2 1/2 and 3 1/2 hours before testing. Barr et al. (1994) analyzed a 1-minute baseline period, with no experimental stimuli, immediately before a sustained crying episode lasting 15 seconds. For the newborns, reported durations of hand-to-mouth contact during 10-second intervals of the 1-minute baseline period were in the range of 0 to 2%. The 5- to 7-week old infants apparently were studied at primary care pediatric facilities when they were in bassinets inclined at an angle of 10 degrees. For these slightly older infants, the baseline periods analyzed were less than 20 seconds in length, but Barr et al. (1994) reported similarly low mean percentages of the 10-second intervals (approximately 1% of the time with hand-to-mouth contact). Hand-to-mouth contact was defined as "any part of the hand touching the lips and/or the inside of the mouth." The researchers performed inter-observer reliability tests on the videotape data and reported a mean inter-observer reliability of 0.78 by Cohen's kappa.

The advantages of this study were that use of video cameras could be expected to have virtually no effect on newborns' or five to seven week old infants' behavior, and that inter-observer reliability tests were performed. The study data did not represent newborn or 5- to 7-week-old infant hand-to-mouth contact during periods in which infants of these ages were in a sleeping or other non-alert state, and data may only represent behavior immediately prior to a state of distress (sustained crying episode). The extent to which these infants' behavior is representative of other full-term infants of these ages is unknown.

4.4.2.2. *Zartarian et al. (1997b)—Quantifying Videotaped Activity Patterns: Video Translation Software and Training Technologies/Zartarian et al. (1997a)—Quantified Dermal Activity Data From a Four-Child Pilot Field Study/Zartarian et al. (1998)—Quantified Mouthing Activity Data From a Four-Child Pilot Field Study*

As described in Section 4.3.1.1, Zartarian et al. (1998, 1997a; 1997b) conducted a pilot study of the video-transcription methodology to investigate the applicability of using videotaping for gathering information related to children's activities, dermal exposures and mouthing behaviors. The researchers had conducted studies using the real-time hand recording methodology. These studies demonstrated poor inter-observer reliability and observer fatigue when attempted for long periods of time. This prompted the investigation into using videotaping with transcription of the children's activities at a point in time after the videotaped observations occurred.

Four Mexican-American farm worker children in the Salinas Valley of California each were videotaped with a hand-held videocamera during their waking hours, excluding time spent in the bathroom, over 1 day in September 1993. The boys were 2 years 10 months old and 3 years 9 months old; the girls were 2 years 5 months old and 4 years 2 months old. Time of videotaping was 6.0 hours for the younger girl, 6.6 hours for the older girl, 8.4 hours for the younger boy and 10.1 hours for the older boy. The videotaping gathered information on detailed micro-activity patterns of children to be used to evaluate software for videotaped activities and translation training methods.

The four children mouthed non-dietary objects an average of 4.35% (range 1.41 to 7.67%) of the total observation time, excluding the time during which the children were out of the camera's view (Zartarian et al., 1998). Objects mouthed included bedding/towels, clothes, dirt, grass/vegetation, hard surfaces, hard toys, paper/card, plush toy, and skin (Zartarian et al., 1998). Frequency distributions for the four children's non-dietary object contact durations were reported to be similar in shape. Reported hand-to-mouth contact presumably is a subset of the object-to-mouth contacts described in Zartarian et al. (1997b), and is described in Zartarian et al. (1997a). The four children mouthed their hands an average of 2.35% (range 1.0 to 4.4%) of observation time (Zartarian et al., 1997a). The researchers reported measures taken to assess inter-observer reliability and several problems with the video-transcription process.

This study's primary purpose was to develop and evaluate the video-transcription methodology; a secondary purpose was collection of mouthing behavior data. The sample of children studied was very small and not likely to be representative of the national population. Thus, U.S. EPA did not judge it to be suitable for consideration as a key study of children's mouthing behavior. As with other video-transcription studies, the presence of non-family member videographers and a video camera may have influenced the children's behavior.

4.4.2.3. *Groot et al. (1998)—Mouthing Behavior of Young Children: An Observational Study*

In this study, Groot et al. (1998) examined the mouthing behavior of 42 Dutch children (21 boys and 21 girls) between the ages of 3 and 36 months in late July and August 1998. Parent observations were made of children in 36 families. Parents were asked to observe their children 10 times per day for 15-minute intervals (i.e., 150 minutes total per day) for two days and measure mouthing times with a stopwatch. In this study, *mouthing* was defined as "all activities in which objects are touched by mouth or put into the mouth except for eating and drinking. This term includes licking as well as sucking, chewing and biting."

For the study, a distinction was made between toys meant for mouthing (e.g., pacifiers, teething rings) and those not meant for mouthing. Inter- and intra-observer reliability was measured by trained observers who co-observed a portion of observation periods in three families and who co-observed and repeatedly observed some video transcriptions made of one child. Another quality assurance procedure performed for the extrapolated total mouthing time data was to select 12 times per hour randomly during the entire waking period of four children during 1 day, in which the researchers recorded activities and total mouthing times.

Although the sample size was relatively small, the results provided estimates of mouthing times, other than pacifier use, during 1 day. The results were extrapolated to the entire day based on the 150 minutes of observation per day, and the mean value for each child for the 2 days of observations was interpreted as the estimate for that child. Table 4-22 shows summary statistics. The standard deviation in all four age categories except the 3- to 6-month old children exceeded the estimated mean. The 3 to 6 month children (N = 5) were estimated to have mean non-pacifier mouthing durations of 36.9 minutes per day, with toys as the most frequently mouthed product category, while the 6 to 12 month children (N = 14) were estimated to have 44 minutes per day (fingers most frequently mouthed). The 12- to 18-month olds' (N = 12) estimated mean non-pacifier mouthing time was 16.4 minutes per day, with fingers most frequently mouthed, and 18- to 36-month olds' (N = 11) estimated mean non-pacifier mouthing time was 9.3 minutes per day (fingers most frequently mouthed).

One strength of this study is that the researchers recognized that observing children might affect their behavior and emphasized to the parents the importance of making observations under conditions that were as normal as possible. In spite of these efforts, many parents perceived that their children's behavior was affected by being observed and that observation interfered with caregiving responsibilities such as comforting children when they were upset. Other limitations included a small sample size that was not representative of the Dutch population and that also may not be representative of U.S. children. Technical problems with the stopwatches affected at least 14 of 36 parents' data.

4.4.2.4. *Smith and Norris (2003)—Reducing the Risk of Choking Hazards: Mouthing Behavior of Children Aged 1 Month to 5 Years/Norris and Smith (2002)—Research Into the Mouthing Behavior of Children up to 5 Years Old*

Smith and Norris (2003) conducted a real-time hand recording study of mouthing behavior among 236 children (111 males, 125 females) in the United Kingdom (exact locations not specified) who were from 1 month to 5 years old. Children were observed at home by parents, who used stopwatches to record the time that mouthing began, the type of mouthing, the type of object being mouthed, and the time that mouthing ceased. Children were observed for a total of 5 hours over a 2-week period; the observation time consisted of twenty 15-minute periods spread over different times and days during the child's waking hours. Parents also recorded the times each child was awake and not eating meals so that the researchers could extrapolate estimates of total daily mouthing time from the shorter observation periods. Mouthing was defined as licking/lip touching, sucking/trying to bite and biting or chewing, with a description of each category, together with pictures, given to parents as guidance for what to record.

Table 4-23 shows the results of the study. While no overall pattern could be found in the different age groups tested, a Kruskal-Wallis test on the data for all items mouthed indicated that there was a significant difference between the age groups. Across all age groups and types of items, licking and sucking accounted for 64% of all mouthing behavior. Pacifiers and fingers exhibited less variety on mouthing behavior (principally sucking), while other items had a higher frequency of licking, biting, or other mouthing.

The researchers randomly selected 25 of the 236 children for a single 15-minute observation of each child (total observation time across all children: 375 minutes), to compare the mouthing frequency and duration data obtained according to the real-time hand recording and the video-transcription methodologies, as well as the reliability of parent observations versus those made by trained professionals. For this group of 25 children, the total number of mouthing behavior events recorded by video (160) exceeded those recorded by parents (114) and trained observers (110). Similarly, the total duration recorded by video (24 minutes and 15 seconds) exceeded that recorded by observers (parents and trained observers both recorded identical totals of 19 minutes and 44 seconds). The mean and standard deviation of observed mouthing time were both lower when recorded by video versus real-time hand recording. The maximum observed mouthing time also was lower (6 minutes and 7 seconds by video vs. 9 minutes and 43 seconds for both parents and trained observers).

The strengths of this study were its comparison of three types of observation (i.e., parents, trained observers, and videotaping), and its detailed reporting of mouthing behaviors by type, object/item mouthed, and age group. However, the children studied may not be representative of U.S. children. In addition, the study design or approach made the data less applicable for exposure assessment purposes (e.g., data on mouthing behavior that was intended to be used in reducing the risk of choking hazards).

4.4.2.5. *AuYeung et al. (2004)—Young Children's Mouthing Behavior: An Observational Study via Videotaping in a Primarily Outdoor Residential Setting*

As described in Section 4.3.1.5, AuYeung et al. (2004) used a video-transcription methodology to study a group of 38 children (20 females and 18 males; ages 1 to 6 years), 37 of whom were selected randomly via a telephone screening survey of a 300- to 400-square-mile portion of the San Francisco, CA peninsula, along with one child selected by convenience because of time constraints. Families who lived in a residence with a lawn and whose annual income was >$35,000 were asked to participate. Videotaping took place between August 1998 and May 1999 for approximately 2 hours per child. Videotaping by one researcher was supplemented with field notes taken by a second researcher who was also present during taping. Most of the videotaping took place during outdoor play, however, data were included for several children (one child <2 years old and 8 children >2 years old) who had more than 15 minutes of indoor play during their videotaping sessions.

The videotapes were translated into ASCII computer files using VirtualTimingDevice™ software described in Zartarian et al. (1997b). Both frequency (see Section 4.3.1.5 of this chapter) and duration were analyzed. Between 5 and 10% of the translated data files were randomly chosen for quality control checks for inter-observer agreement. Ferguson et al. (2006) described quality control aspects of the study in detail.

For analysis, the mouthing contacts were divided into indoor and outdoor locations and 16 object/surface categories. Mouthing durations were analyzed by age and sex separately and in combination. *Mouthing contacts* were defined as contact with the lips, inside of the mouth, and/or the tongue; dietary contacts were ignored. Table 4-24 shows mouthing durations (outdoor locations). For the children in all age groups, the median duration of each mouthing contact was 1 to 2 seconds, confirming the observations of other researchers that children's mouthing contacts are of very short duration. For the one child observed that was ≤24 months, the total indoor mouthing duration was 11.1 minutes/hour; for children >24 months, the median indoor mouthing duration was 0.9 minutes/hour (see Table 4-25). For outdoor environments, median contact durations for these age groups decreased to 0.8 and 0.6 minutes/hour, respectively (see Table 4-26).

Non-parametric tests, such as the Wilcoxon rank sum test, were used for the data analyses. Both age and sex were found to be associated with differences in mouthing behavior. Girls' hand-to-mouth contact durations were significantly shorter than for boys (p = 0.04).

This study provides distributions of outdoor mouthing durations with various objects and surfaces. Although indoor mouthing data were also included in this study, the results were based on a small number of children (N = 9) and a limited amount of indoor play. The sample of children may be representative of certain socioeconomic strata in the study area, but is not likely to be representative of the national population. Because of the children's ages, the presence of unfamiliar persons following the children with a video camera may have influenced the video-transcription methodology results.

4.5. MOUTHING PREVALENCE STUDIES

4.5.1. Stanek et al. (1998)—Prevalence of Soil Mouthing/Ingestion Among Healthy Children Aged 1 to 6

Stanek et al. (1998) characterized the prevalence of mouthing behavior among healthy children based on a survey response study of parents or guardians of 533 children (289 females, 244 males) ages 1 to 6 years old. Study participants were attendees at scheduled well-child visits at three clinics in western Massachusetts in August through October, 1992. Participants were questioned about the frequency of 28 mouthing behaviors of the children over the preceding month in addition to exposure time (e.g., time outdoors, play in sand or dirt) and children's characteristics (e.g., teething).

Table 4-27 presents the prevalence of reported non-food ingestion/mouthing behaviors by child's age as the percentage of children whose parents reported the behavior in the preceding month. The table includes a column of data for the 3 to <6 year age category; this column was calculated by U.S. EPA as a weighted mean value of the individual data for 3-, 4-, and 5-year olds in order to conform to the standardized age categories used in this handbook. Among all the age groups, 1-year olds had the highest reported daily sucking of fingers/thumb; the proportion dropped for 2-year olds, but rose slightly for 3- and 4-year olds and declined again after age 4. A similar pattern was reported for more than weekly finger/thumb sucking, while more than monthly finger/thumb sucking showed a very slight increase for 6-year olds. Reported pacifier use was highest for 1-year olds and declined with age for daily and more than weekly use; for more than monthly use of a pacifier several 6-year olds were reported to use pacifiers, which altered the age-declining pattern for the daily and more than weekly reported pacifier use. A pattern similar to pacifier use existed with reported mouthing of teething toys, with highest reported use for 1-year olds, a decline with age until age 6 when reported use for daily, more than weekly, and more than monthly use of teething toys increased.

The authors developed an outdoor mouthing rate for each child as the sum of rates for responses to four questions on mouthing specific outdoor objects. Survey responses were converted to mouthing rates per week, using values of 0, 0.25, 1, and 7 for responses of never, monthly, weekly, and daily ingestion. Reported outdoor soil mouthing behavior prevalence was found to be higher than reported indoor dust mouthing prevalence, but both behaviors had the highest reported prevalence among 1-year old children and decreased for children 2 years and older. The investigators conducted principal component analyses on responses to four questions relating to ingestion/mouthing of outdoor objects in an attempt to characterize variability. Outdoor ingestion/mouthing rates constructed from the survey responses were that children 1-year old were reported to mouth or ingest outdoor objects 4.73 times per week while 2- to 6-year olds were reported to mouth or ingest outdoor objects 0.44 times per week. The authors developed regression models to identify factors related to high outdoor mouthing rates. The authors found that children who were reported to play in sand or dirt had higher outdoor object ingestion/mouthing rates.

A strength of this study is that it was a large sample obtained in an area with urban and semi-urban residents within various socioeconomic categories and with varying racial and ethnic identities. However, difficulties with parents' recall of past events may have caused either over-estimates or under-estimates of the behaviors studied.

4.5.2. Warren et al. (2000)—Non-Nutritive Sucking Behaviors in Preschool Children: A Longitudinal Study

Warren et al. (2000) conducted a survey response study of a non-random cohort of children born in certain Iowa hospitals from early 1992 to early 1995 as part of a study of children's fluoride exposure. For this longitudinal study of children's non-nutritive sucking behaviors, 1,374 mothers were recruited at the time of their newborns' birth, and more than 600 were active in the study until the children were at least 3 years old. Survey questions on non-nutritive sucking behaviors were administered to the mothers when the children were 6 weeks, and 3, 6, 9, 12, 16, and 24 months old, and then yearly after age 24 months. Questions were posed regarding the child's sucking behavior during the previous 3 to 12 months.

The authors reported that nearly all children sucked non-nutritive items, including pacifiers, thumbs or other fingers, and/or other objects, at some point in their early years. The parent-reported sucking behavior prevalence peaked at 91% for 3 month old children. At 2 years of age, a majority (53%) retained a sucking habit, while 29% retained the habit at age 3 years and 21% at age 4 years. Parent-reported pacifier use was 28% for 1-year olds, 25% for 2-year olds, and 10% for 3-year olds. The authors cautioned against generalizing the results to other children because of study design limitations.

Strengths of this study were its longitudinal design and the large sample size. A limitation is that the non-random selection of original study participants and the self-selected nature of the cohort of survey respondents who participated over time means that the results may not be representative of other U.S. children of these ages.

4.6. REFERENCES FOR CHAPTER 4

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Table 4-3. New Jersey Children's Mouthing Frequency (contacts/hour) From Video-Transcription

Category	Minimum	Mean	Median	90th Percentile	Maximum
Hand to mouth	0.4	9.5	8.5	20.1	25.7
Object to mouth	0	16.3	3.6	77.1	86.2

Source: Reed et al. (1999).

Table 4-4. Survey-Reported Percent of 168 Minnesota Children Exhibiting Behavior, by Age

Age Group (years)	Thumbs/Fingers in Mouth	Toes in Mouth	Non-Food Items in Mouth
3	71	29	71
4	63	0	31
5	33	-	20
6	30	-	29
7	28	-	28
8	33	-	40
9	43	-	38
10	38	-	38
11	33	-	48
12	33	-	17

\- = No data.

Source: Freeman et al. (2001).

Table 4-5. Video-Transcription Median (Mean) Observed Mouthing in 19 Minnesota Children (contacts/hour), by Age

Age Group (years)	*N*	Object-to-Mouth[a]	Hand-to-Mouth
3 to 4	3	3 (6)	3.5 (4)
5 to 6	7	0 (1)	2.5 (8)
7 to 8	4	0 (1)	3 (5)
10 to 12	5	0 (1)	2 (4)

[a] Kruskal Wallis test comparison across four age groups, $p = 0.002$.
N = Number of observations.

Source: Freeman et al. (2001).

Table 4-6. Variability in Objects Mouthed by Washington State Children (contacts/hour)

Variable	All Subjects				≤24 Months				>24 Months			
	N[a]	Mean[b]	Median	95% CI[c]	*N*[a]	Mean[b]	Median	95% CI[c]	*N*[a]	Mean[b]	Median	95% CI[c]
Mouth to body	186	8	2	2−3	69	10	4	3−6	117	7	1	0.8−1.3
Mouth to hand	186	16	11	9−14	69	18	12	9−16	117	16	9	7−12
Mouth to surface	186	4	1	0.8−1.2	69	7	5	3−8	117	2	1	0.9−1.1
Mouth to toy	186	27	18	14−23	69	45	39	31−48	117	17	9	7−12
Total events	186	56	44	36−52	69	81	73	60−88	117	42	31	25−39

[a] Number of observations.
[b] Arithmetic mean.
[c] The 95% confidence intervals (CI) apply to median. Values were calculated in logs and converted to original units.

Source: Tulve et al. (2002).

Table 4-7. Indoor Mouthing Frequency (contacts per contacts/hour), Video-Transcription of 9 Children, by Age

Age Group	*N*	Statistic	Hand	Total Non-Dietary[a]
13 to 84 months	9	Mean	20.5	29.6
		Median	14.8	22.1
		Range	2.5−70.4	3.2−82.2
≤24 months	1	-	73.5	84.8
>24 months	8	Mean	13.9	22.7
		Median	13.3	19.5
		Range	2.2−34.1	2.8−51.3

[a] Object/surface categories mouthed indoors included: clothes/towels, hands, metal, paper/wrapper, plastic, skin, toys, and wood.

N = Number of subjects.

Source: AuYeung et al. (2004).

Table 4-8. Outdoor Mouthing Frequency (contacts per contacts/hour), Video-Transcription of 38 Children, by Age

Age Group	*N*	Statistic	Hand	Total Non-Dietary[a]
13 to 84 months	38	Mean	11.7	18.3
		5th percentile	0.4	0.8
		25th percentile	4.4	9.2
		50th percentile	8.4	14.5
		75th percentile	14.8	22.4
		95th percentile	31.5	51.7
		99th percentile	47.6	56.6
≤24 months	8	Mean	13.0	20.4
		Median	7.0	13.9
		Range	1.3−47.7	6.2−56.4
>24 months	30	Mean	11.3	17.7
		5th percentile	0.2	0.6
		25th percentile	4.7	7.6
		50th percentile	8.6	14.6
		75th percentile	14.8	22.4
		95th percentile	27.7	43.8
		99th percentile	39.5	53.0

[a] Object/surface categories mouthed outdoors included: animal, clothes/towels, fabric, hands, metal, non-dietary water, paper/wrapper, plastic, skin, toys, vegetation/grass, and wood.

N = Number of subjects.

Source: AuYeung et al. (2004).

Table 4-9. Videotaped Mouthing Activity of Texas Children, Median Frequency (Mean ± SD), by Age

Age	*N*	Hand-to-Mouth (contact/hour)	Object-to-Mouth (contact/hour)
		Median (Mean ± SD) Frequency	Median (Mean ± SD) Frequency
7 to 12 months	13	14 (19.8 ± 14.5)	18.1 (24.4 ± 11.6)
13 to 24 months	12	13.3 (15.8 ± 8.7)	8.4 (9.8 ± 6.3)
25 to 36 months	18	9.9 (11.9 ± 9.3)	5.5 (7.8 ± 5.8)
37 to 53 months	9	19.4 (22.1 ± 22.1)	8.4 (10.1 ± 12.4)

N = Number of subjects.
SD = Standard deviation.

Source: Black et al. (2005).

Table 4-10. Indoor Hand-to-Mouth Frequency (contacts/hour) Weibull Distributions From Various Studies, by Age

Age Group	Weibull Scale Parameter	Weibull Shape Parameter	Chi-Square	*N*	Mean	SD	Percentile				
							5	25	50	75	95
3 to <6 months	1.28	30.19	fail	23	28.0	21.7	3.0	8.0	23.0	48.0	65.0
6 to <12 months	1.02	19.01	pass	119	18.9	17.4	1.0	6.6	14.0	26.4	52.0
1 to <2 years	0.91	18.79	fail	245	19.6	19.6	0.1	6.0	14.0	27.0	63.0
2 to <3 years	0.76	11.04	fail	161	12.7	14.2	0.1	2.9	9.0	17.0	37.0
3 to <6 years	0.75	12.59	pass	169	14.7	18.4	0.1	3.7	9.0	20.0	54.0
6 to <11 years	1.36	7.34	pass	14	6.7	5.5	1.7	2.4	5.7	10.2	20.6

N = Number of subjects.
SD = Standard deviation.

Source: Xue et al. (2007).

Table 4-11. Outdoor Hand-to-Mouth Frequency (contacts/hour) Weibull Distributions From Various Studies, by Age

Age Group	Weibull Scale Parameter	Weibull Shape Parameter	Chi-Square	*N*	Mean	SD	Percentile				
							5	25	50	75	95
6 to <12 months	1.39	15.98	pass	10	14.5	12.3	2.4	7.6	11.6	16.0	46.7
1 to <2 years	0.98	13.76	pass	32	13.9	13.6	1.1	4.2	8.0	19.2	42.2
2 to <3 years	0.56	3.41	fail	46	5.3	8.1	0.1	0.1	2.6	7.0	20.0
3 to <6 years	0.55	5.53	fail	55	8.5	10.7	0.1	0.1	5.6	11.0	36.0
6 to <11 years	0.49	1.47	fail	15	2.9	4.3	0.1	0.1	0.5	4.7	11.9

N = Number of subjects.
SD = Standard deviation.

Source: Xue et al. (2007).

Table 4-12. Object/Surface-to-Mouth Contact Frequency for Infants and Toddlers (events/hour) (*N* = 23)								
			Percentiles					
Object/Surface	Range	Mean	5th	25th	50th	75th	95th	99th
Animal	-	-	-	-	-	-	-	-
Body	0.0−5.0	1.5	0.0	0.4	0.8	2.4	4.0	4.8
Clothes/towel	0.3−13.6	5.4	1.1	2.6	3.6	6.9	13.2	13.5
Fabric	0.0−5.7	1.1	0.0	0.0	0.3	2.2	3.3	5.2
Floor	0.0−1.3	0.2	0.0	0.0	0.0	0.4	1.0	1.2
Food	2.3−68.3	28.9	11.1	17.8	28.2	34.8	53.7	65.2
Footwear	0.0−8.9	0.7	0.0	0.0	0.0	0.0	5.7	8.3
Hand/mouth	2.0−62.1	18.4	6.6	10.0	15.2	22.8	44.7	58.6
Metal	0.0−2.1	0.3	0.0	0.0	0.0	0.1	1.3	1.9
Non-dietary water	-	-	-	-	-	-	-	-
Paper/wrapper	0.0−13.6	2.1	0.0	0.3	0.8	2.1	7.2	12.2
Plastic	0.0−14.3	2.0	0.0	0.4	1.4	2.3	5.1	12.3
Rock/brick	-	-	-	-	-	-	-	-
Toy	0.3−48.4	14.7	1.9	6.8	12.5	20.6	34.9	45.6
Vegetation	0.0−18.2	0.8	0.0	0.0	0.0	0.0	0.0	14.2
Wood	0.0−3.9	0.5	0.0	0.0	0.0	0.5	1.8	3.4
Non-dietary object[a]	6.2−82.3	29.2	8.1	15.9	27.2	38.0	64.0	78.8
All objects/surfaces	24.4−145.9	76.5	28.7	58.7	77.4	94.5	123.1	141.2

[a] All object designations except for food and hand/mouth represent non-dietary objects.

\- No mouth contact with these objects/surfaces occurred.

Source: Beamer et al. (2008).

Table 4-13. Distributions Mouthing Frequency and Duration for Non-Dietary Objects With Significant Differences (p < 0.05) Between Infants and Toddlers

Object/Surface	Infant (6 to 13 months) Mouthing Frequency (contacts/hour)								Infant (6 to 13 months) Mouthing Duration (minutes/hour)							
	N	Range	Mean	5th	25th	50th	75th	95th	99th	Range	Mean	5th	25th	50th	75th	95th	99th
Clothes/towel	13	2−13.3	6.8	2.7	4.8	6.3	7.2	12.7	12.1	-	-	-	-	-	-	-	-
Paper/wrapper	13	0.0−7.2	1.1	0.0	0.2	0.7	0.8	4.3	6.6	0.0−0.7	0.1	0.0	0.0	0.0	0.1	0.4	0.6
Toy	13	6.5−48.4	21.1	7.3	14.4	20.2	25.5	40.8	46.9	0.7−17.9	3.6	0.8	1.2	1.7	2.8	11.6	16.6
Non-dietary object/surface	13	14−82.3	37.8	20.0	28.3	35.2	38.6	72.8	64.0	1.1−18.4	4.5	1.2	2.2	2.8	4.1	12.6	17.2
	Toddler (20−26 months) Mouthing Frequency (contacts/hour)								Toddler (20−26 months) Mouthing Duration (minutes/hour)							
	N	Range	Mean	5th	25th	50th	75th	95th	99th	Range	Mean	5th	25th	50th	75th	95th	99th
Clothes/towel	10	0.3−13.6	3.5	0.6	2.0	2.6	3.6	9.1	12.7	-	-	-	-	-	-	-	-
Paper/wrapper	10	0.3−12.6	6.3	1.0	2.8	5.4	9.6	12.5	12.6	0.0−0.8	0.2	0.0	0.0	0.1	0.2	0.6	0.7
Toy	10	0.3−13.6	3.5	0.6	2.0	2.6	3.6	9.1	12.7	0.0−6.8	1.5	0.1	0.2	0.5	0.7	6.1	6.6
Other non-dietary object/surface[a]	10	6.2−41.2	18.0	7.0	9.4	15.9	22.0	35.2	40.5	0.3−6.9	2.1	0.4	0.7	1.3	1.8	6.3	6.7

[a] Excludes “clothes/towel,” “paper/wrapper,” and “toys;” includes all other non-dietary objects/surfaces shown in Table 4-12.
\- No significant difference between infants and toddlers for this object/surface category.

Source: Beamer et al. (2008) supplemental data.

Table 4-14. Indoor Object-to-Mouth Frequency (contacts/hour) Weibull Distributions From Various Studies, by Age												
Age Group	Weibull Scale Parameter	Weibull Shape Parameter	Chi-Square	*N*	Mean	SD	Percentile				
							5th	25th	50th	75th	95th
3 to <6 months	9.83	0.74	pass	19	11.2	10.0	0.1	1.7	9.3	17.3	31.8
6 to <12 months	22.72	1.66	pass	82	20.3	12.5	3.3	11.3	19.0	28.0	37.9
1 to <2 years	15.54	1.39	pass	137	14.2	10.2	2.0	6.5	12.3	19.0	34.0
2 to <3 years	10.75	1.36	pass	95	9.9	7.0	1.7	4.2	8.7	14.5	24.4
3 to <6 years	6.90	0.58	pass	167	10.1	14.8	0.1	1.0	5.0	13.0	39.0
6 to <11 years	1.04	0.85	pass	14	1.1	1.1	0.1	0.1	0.9	1.985	3.2

N = Number of subjects.
SD = Standard deviation.

Source: Xue et al. (2010).

Table 4-15. Outdoor Object-to-Mouth Frequency (contacts/hour) Weibull Distributions From Various Studies, by Age											
Age Group (years)	Weibull Scale Parameter	Weibull Shape Parameter	Chi-Square	*N*	Mean	SD	Percentile				
							5th	25th	50th	75th	95th
1 to <2	8.58	0.93	pass	21	8.8	8.8	0.1	3.8	6.0	10.8	21.3
2 to <3	6.15	0.64	pass	29	8.1	10.5	0.1	1.5	4.6	11.0	40.0
3 to <6	5.38	0.55	pass	53	8.3	12.4	0.1	0.1	5.0	10.6	30.3
6 to <11	1.10	0.55	fail	29	1.9	2.8	0.1	0.1	0.8	2.0	9.1

N = Number of subjects.
SD = Standard deviation.

Source: Xue et al. (2010).

Table 4-16. Survey-Reported Mouthing Behaviors for 92 Washington State Children												
Behavior	Never		Seldom		Occasionally		Frequently		Always		Unknown	
	N	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%
Hand/foot in mouth	4	4	27	30	23	25	31	34	4	4	3	3
Pacifier	74	81	6	7	2	2	9	10	1	1	0	0
Mouth on object	14	15	30	33	25	27	19	21	1	1	3	3
Non-food in mouth	5	5	25	27	33	36	24	26	5	5	0	0
Eat dirt/sand	37	40	39	43	11	12	4	4	1	1	0	0

N = Number of subjects.

Source: Davis et al. (1995).

Table 4-17. Number of Hand Contacts Observed in Adults During a Continuous 3-Hour Period				
Subject	Eye	Lip	Nostril	Total
1	0	0	3	3
2	4	2	1	7
3	2	12	4	18
4	1	1	20	22
5	10	22	15	47
6	13	33	8	54
7	17	15	27	59
8	6	31	28	65
9	9	52	30	91
10	12	72	20	104
Mean	7.4	24	16	47
Standard Deviation	5.7	24	11	35

Source: Nicas and Best (2008).

Table 4-18. Estimated Daily Mean Mouthing Times of New York State Children, for Pacifiers and Other Objects

Object Type	Age 0 to 18 Months		Age 19 to 36 Months	
	All Children	Only Children Who Mouthed Object[a]	All Children	Only Children Who Mouthed Object[a]
	Minutes/Day	Minutes/Day	Minutes/Day	Minutes/Day
Pacifier	108 (*N* = 107)	221 (*N* = 52)	126 (*N* = 110)	462 (*N* = 52)
Teether	6 (*N* = 107)	20 (*N* = 34)	0 (*N* = 110)	30 (*N* = 1)
Plastic toy	17 (*N* = 107)	28 (*N* = 66)	2 (*N* = 110)	11 (*N* = 21)
Other objects	9 (*N* = 107)	22 (*N* = 46)	2 (*N* = 110)	15 (*N* = 18)

[a] Refers to means calculated for the subset of the sample children who mouthed the object stated (zeroes are eliminated from the calculation of the mean).

N = Number of children.

Source: Juberg et al. (2001).

Table 4-19. Percent of Houston-Area and Chicago-Area Children Observed Mouthing, by Category and Child's Age

Object Category	All Ages	<1 Year	1 to 2 Years	2 to 3 Years
All objects	100	100	100	100
Pacifier	27	43	27	10
Non-pacifier	100	100	100	100
Soft plastic food content item	28	13	30	41
Anatomy	99	100	97	100
Non-soft plastic toy, teether, and rattle	91	94	91	86
Other items	98	98	97	98

Source: Greene (2002).

Table 4-20. Estimates of Mouthing Time for Various Objects for Infants and Toddlers (minutes/hour), by Age				
Age Group	Mean (SD)	Median	95th Percentile	99th Percentile
		All Items[a]		
3 to <12 months	10.5 (7.3)	9.6	26.2	39.8
12 to <24 months	7.3 (6.8)	5.5	22.0	28.8
24 to <36 months	5.3 (8.2)	2.4	15.6	47.8
		Non-Pacifier[b]		
3 to <12 months	7.1 (3.6)	6.9	13.1	14.4
12 to <24 months	4.7 (3.7)	3.6	12.8	18.9
24 to <36 months	3.5 (3.6)	2.3	12.8	15.6
		All Soft Plastic Item[c]		
3 to <12 months	0.5 (0.6)	0.1	1.8	2.5
12 to <24 months	0.4 (0.4)	0.2	1.3	1.9
24 to <36 months	0.4 (0.6)	0.1	1.6	2.9
		Soft Plastic Item Not Food Contact		
3 to <12 months	0.4 (0.6)	0.1	1.8	2.0
12 to <24 months	0.3 (0.4)	0.1	1.1	1.5
24 to <36 months	0.2 (0.4)	0.0	1.3	1.8
		Soft Plastic Toy, Teether, and Rattle		
3 to <12 months	0.3 (0.5)	0.1	1.8	2.0
12 to <24 months	0.2 (0.3)	0.0	0.9	1.3
24 to <36 months	0.1 (0.2)	0.0	0.2	1.6
		Soft Plastic Toy		
3 to <12 months	0.1 (0.3)	0.0	0.7	1.1
12 to <24 months	0.2 (0.3)	0.0	0.9	1.3
24 to <36 months	0.1 (0.2)	0.0	0.2	1.6
		Soft Plastic Teether and Rattle		
3 to <12 months	0.2 (0.4)	0.0	1.0	2.0
12 to <24 months	0.0 (0.1)	0.0	0.1	0.6
24 to <36 months	0.0 (0.1)	0.0	0.0	1.0
		Other Soft Plastic Item		
3 to <12 months	0.1 (0.2)	0.0	0.8	1.0
12 to <24 months	0.1 (0.1)	0.0	0.4	0.6
24 to <36 months	0.1 (0.3)	0.0	0.5	1.4
		Soft Plastic Food Contact Item		
3 to <12 months	0.0 (0.2)	0.0	0.3	0.9
12 to <24 months	0.1 (0.2)	0.0	0.7	1.2
24 to <36 months	0.2 (0.4)	0.0	1.2	1.9
		Anatomy		
3 to <12 months	2.4 (2.8)	1.5	10.1	12.2
12 to <24 months	1.7 (2.7)	0.8	8.3	14.8
24 to <36 months	1.2 (2.3)	0.4	5.1	13.6

Table 4-20. Estimates of Mouthing Time for Various Objects for Infants and Toddlers (minutes/hour), by Age (continued)

Age Group	Mean (SD)	Median	95th Percentile	99th Percentile
Non-Soft Plastic Toy, Teether, and Rattle				
3 to <12 months	1.8 (1.8)	1.3	6.5	7.7
12 to <24 months	0.6 (0.8)	0.3	1.8	4.6
24 to <36 months	0.2 (0.4)	0.1	0.9	2.3
Other Item				
3 to <12 months	2.5 (2.1)	2.1	7.8	8.1
12 to <24 months	2.1 (2.0)	1.4	6.6	9.0
24 to <36 months	1.7 (2.6)	0.7	7.1	14.3
Pacifier				
3 to <12 months	3.4 (6.9)	0.0	19.5	37.3
12 to <24 months	2.6 (6.5)	0.0	19.9	28.6
24 to <36 months	1.8 (7.9)	0.0	4.8	46.3

[a] Object category "all items" is subdivided into pacifiers and non-pacifiers.

[b] Object category "non-pacifiers" is subdivided into all soft plastic items, anatomy (which includes hair, skin, fingers and hands), non-soft plastic toys/teethers/rattles, and other items.

[c] Object category "all soft plastic items" is subdivided into food contact items, non-food contact items (toys, teethers, and rattles) and other soft plastic.

SD = Standard deviation.

Source: Greene (2002).

Table 4-21. Object/Surface-to-Hands and Mouth Contact Duration for Infants and Toddlers (minutes/hour) (*N* = 23)

Object/Surface	Range	Mean	Percentiles					
			5th	25th	50th	75th	95th	99th
Animal	-	-	-	-	-	-	-	-
Body	0.0−0.3	0.1	0.0	0.0	0.0	0.1	0.3	0.3
Clothe/towel	0.0−0.9	0.3	0.0	0.1	0.2	0.4	0.7	0.9
Fabric	0.0−0.2	0.0	0.0	0.0	0.0	0.1	0.2	0.2
Floor	0.0−0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Food	0.3−15.0	4.7	0.4	1.8	3.8	6.6	10.9	14.1
Footwear	0.0−1.4	0.1	0.0	0.0	0.0	0.0	0.3	1.1
Hand/mouth	0.2−5.4	1.4	0.4	0.5	1.2	1.8	3.7	5.0
Metal	0.0−0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.2
Non-dietary water	-	-	-	-	-	-	-	-
Paper/wrapper	0.0−0.8	0.1	0.0	0.0	0.0	0.1	0.7	0.8
Plastic	0.0−0.6	0.1	0.0	0.0	0.1	0.1	0.5	0.6
Rock/brick	-	-	-	-	-	-	-	-
Toys	0.0−17.9	2.7	0.1	0.6	1.2	2.8	7.4	15.6
Vegetation	0.0−0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Wood	0.0−0.3	0.0	0.0	0.0	0.0	0.0	0.2	0.3
Non-dietary object[a]	0.3−18.4	3.5	0.5	1.2	2.2	3.9	8.5	16.3
All objects/surfaces	2.2−33.6	9.6	2.4	5.1	8.8	12.0	17.1	30.0

[a] All object designations except for food and hand/mouth represent non-dietary objects.

\- No mouth contact with these objects/surfaces occurred.

Source: Beamer et al. (2008).

Table 4-22. Mouthing Times of Dutch Children Extrapolated to Total Time While Awake, Without Pacifier (minutes/day), by Age

Age Group	*N*	Mean	SD	Minimum	Maximum
3 to 6 months	5	36.9	19.1	14.5	67
6 to 12 months	14	44	44.7	2.4	171.5
12 to 18 months	12	16.4	18.2	0	53.2
18 to 36 months	11	9.3	9.8	0	30.9

Note: The object most mouthed in all age groups was the fingers, except for the 6 to 12 month group, which mostly mouthed toys.

N = Number of children.

SD = Standard deviation.

Source: Groot et al. (1998).

Table 4-23. Estimated Mean Daily Mouthing Duration by Age Group for Pacifiers, Fingers, Toys, and Other Objects (hours:minutes:seconds)

Item Mouthed		Age Group											
		1 to 3 months	3 to 6 months	6 to 9 months	9 to 12 months	12 to 15 months	15 to 18 months	18 to 21 Months	21 to 24 months	2 years	3 years	4 years	5 years
	N =	9	14	15	17	16	14	16	12	39	31	29	24
Dummy (pacifier)		0:47:13	0:27:45	0:14:36	0:41:39	1:00:15	0:25:22	1:09:02	0:25:12	0:32:55	0:48:42	0:16:40	0:00:20
Finger		0:18:22	0:49:03	0:16:54	0:14:07	0:08:24	0:10:07	0:18:40	0:35:34	0:29:43	0:34:42	0:19:26	0:44:06
Toy		0:00:14	0:28:20	0:39:10	0:23:04	0:15:18	0:16:34	0:11:07	0:15:46	0:12:23	0:11:37	0:03:11	0:01:53
Other object		0:05:14	0:12:29	0:24:30	0:16:25	0:12:02	0:23:01	0:19:49	0:12:53	0:21:46	0:15:16	0:10:44	0:10:00
Not recorded		0:00:45	0:00:24	0:00:00	0:00:01	0:00:02	0:00:08	0:00:11	0:14:13	0:02:40	0:00:01	0:00:05	0:02:58
Total (all objects)		1:11:48	1:57:41	1:35:11	1:35:16	1:36:01	0:15:13	1:58:49	1:43:39	1:39:27	1:50:19	0:50:05	0:59:17

N = Number of children in sample.

Source: Smith and Norris (2003).

Table 4-24. Outdoor Median Mouthing Duration (seconds/contact), Video-Transcription of 38 Children, by Age

Age Group	*N*	Statistic	Hand	Total Non-Dietary[a]
13 to 84 months	38	Mean	3.5	3.4
		5th percentile	0	0
		25th percentile	1	1
		50th percentile	1	1
		75th percentile	2	3
		95th percentile	12	11
		99th percentile	41.6	40
≤24 months	8	Mean	9	7
		Median	3	2
		Range	0 to 136	0 to 136
>24 months	30	Mean	2	2.4
		5th percentile	0	0
		25th percentile	1	1
		50th percentile	1	1
		75th percentile	2	2
		95th percentile	5	7
		99th percentile	17.4	24.6

[a] Object/surface categories mouthed outdoors included: animal, clothes/towels, fabric, hands, metal, non-dietary water, paper/wrapper, plastic, skin, toys, vegetation/grass, and wood.

N = Number of subjects.

Source: AuYeung et al. (2004).

Table 4-25. Indoor Mouthing Duration (minutes/hour), Video-Transcription of Nine Children With >15 Minutes in View Indoors

Age Group	*N*	Statistic	Hand	Total Non-Dietary[a]
13 to 84 months	9	Mean	1.8	2.3
		Median	0.7	0.9
		Range	0−10.7	0−11.1
≤24 months	1	Observation	10.7	11.1
>24 months	8	Mean	0.7	1.2
		Median	0.7	0.9
		Range	0−1.9	0−3.7

[a] Object/surface categories mouthed indoors included: clothes/towels, hands, metal, paper/wrapper, plastic, skin, toys, and wood.

N = Number of subjects.

Source: AuYeung et al. (2004).

Table 4-26. Outdoor Mouthing Duration (minutes/hour), Video-Transcription of 38 Children, by Age

Age Group	*N*	Statistic	Hand	Total Non-Dietary[a]
13 to 84 months	38	Mean	0.9	1.2
		5th percentile	0	0
		25th percentile	0.1	0.2
		50th percentile	0.2	0.6
		75th percentile	0.6	1.2
		95th percentile	2.6	2.9
		99th percentile	11.2	11.5
		Range	0−15.5	0−15.8
≤24 months	8	Mean	2.7	3.1
		5th percentile	0	0.2
		25th percentile	0.2	0.2
		50th percentile	0.4	0.8
		75th percentile	1.5	3.1
		95th percentile	11.5	11.7
		99th percentile	14.7	15
		Range	0−15.5	0.2−15.8
>24 months	30	Mean	0.4	0.7
		5th percentile	0	0
		25th percentile	0.1	0.2
		Median	0.2	0.6
		75th percentile	0.4	1
		95th percentile	1.2	2.1
		99th percentile	2.2	2.5
		Range	0−2.4	0−2.6

[a] Object/surface categories mouthed outdoors included: animal, clothes/towels, fabric, hands, metal, non-dietary water, paper/wrapper, plastic, skin, toys, vegetation/grass, and wood.

N = Number of subjects.

Source: AuYeung et al. (2004).

Table 4-27. Reported Daily Prevalence of Massachusetts Children's Non-Food Mouthing/Ingestion Behaviors

Object or Substance Mouthed or Ingested	Percent of Children Reported to Mouth/Ingest Daily				
	1 Year *N* = 171	2 Years *N* = 70	3 to <6 Years[a] *N* = 265	6 Years *N* = 22	All Years *N* = 528
Grass, leaf, flower	16	0	1	0	6
Twig, stick, woodchip	12	0	0	0	4
Teething toy	44	6	2	9	17
Other toy	63	27	12	5	30
Blanket, cloth	29	11	10	5	16
Shoes, Footwear	20	1	0	0	7
Clothing	25	7	9	14	14
Crib, chair, furniture	13	3	1	0	5
Paper, cardboard, tissue	28	9	5	5	13
Crayon, pencil, eraser	19	17	5	18	12
Toothpaste	52	87	89	82	77
Soap, detergent, shampoo	15	14	2	0	8
Plastic, plastic wrap	7	4	1	0	3
Cigarette butt, tobacco	4	0	1	0	2
Suck finger/thumb	44	21	24	14	30
Suck feet or toe	8	1	0	0	3
Bite nail	2	7	10	14	7
Use pacifier	20	6	2	0	9

[a] Weighted mean of 3-, 4-, and 5-year-olds' data calculated by U.S. EPA to conform to standardized age categories used in this handbook.

Source: Stanek et al. (1998).

5. SOIL AND DUST INGESTION

5.1. INTRODUCTION

The ingestion of soil and dust is a potential route of exposure for both adults and children to environmental chemicals. Children, in particular, may ingest significant quantities of soil due to their tendency to play on the floor indoors and on the ground outdoors and their tendency to mouth objects or their hands. Children may ingest soil and dust through deliberate hand-to-mouth movements, or unintentionally by eating food that has dropped on the floor. Adults may also ingest soil or dust particles that adhere to food, cigarettes, or their hands. Thus, understanding soil and dust ingestion patterns is an important part of estimating overall exposures to environmental chemicals.

At this point in time, knowledge of soil and dust ingestion patterns within the United States is somewhat limited. Only a few researchers have attempted to quantify soil and dust ingestion patterns in U.S. adults or children.

This chapter explains the concepts of soil ingestion, soil pica, and geophagy, defines these terms for the purpose of this handbook's exposure factors, and presents available data from the literature on the amount of soil and dust ingested.

The Centers for Disease Control and Prevention's Agency for Toxic Substances and Disease Registry (ATSDR) held a workshop in June 2000 in which a panel of soil ingestion experts developed definitions for soil ingestion, soil-pica, and geophagy, to distinguish aspects of soil ingestion patterns that are important from a research perspective (ATSDR, 2001). This chapter uses the definitions that are based on those developed by participants in that workshop:

Soil ingestion is the consumption of soil. This may result from various behaviors including, but not limited to, mouthing, contacting dirty hands, eating dropped food, or consuming soil directly.

Soil-pica is the recurrent ingestion of unusually high amounts of soil (i.e., on the order of 1,000−5,000 mg/day or more).

Geophagy is the intentional ingestion of earths and is usually associated with cultural practices.

Some studies are of a behavior known as "pica," and the subset of "pica" that consists of ingesting soil. A general definition of the concept of pica is that of ingesting non-food substances, or ingesting large quantities of certain particular foods. Definitions of pica often include references to recurring or repeated ingestion of these substances. Soil-pica is specific to ingesting materials that are defined as soil, such as clays, yard soil, and flower-pot soil. Although soil-pica is a fairly common behavior among children, information about the prevalence of pica behavior is limited. Gavrelis et al. (2011) reported that the prevalence of non-food substance consumption varies by age, race, and income level. The behavior was most prevalent among children 1 to <3 years (Gavrelis et al., 2011). Geophagy, on the other hand, is an extremely rare behavior, especially among children, as is soil-pica among adults. One distinction between geophagy and soil-pica that may have public health implications is the fact that surface soils generally are not the main source of geophagy materials. Instead, geophagy is typically the consumption of clay from known, uncontaminated sources, whereas soil-pica involves the consumption of surface soils, usually the top 2−3 inches (ATSDR, 2001).

Researchers in many different disciplines have hypothesized motivations for human soil-pica or geophagy behavior, including alleviating nutritional deficiencies, a desire to remove toxins or self-medicate, and other physiological or cultural influences (Danford, 1982). Bruhn and Pangborn (1971) and Harris and Harper (1997) suggest a religious context for certain geophagy or soil ingestion practices. Geophagy is characterized as an intentional behavior, whereas soil-pica should not be limited to intentional soil ingestion, primarily because children can consume large amounts of soil from their typical behaviors and because differentiating intentional and unintentional behavior in young children is difficult (ATSDR, 2001). Some researchers have investigated populations that may be more likely than others to exhibit soil-pica or geophagy behavior on a recurring basis. These populations might include pregnant women who exhibit soil-pica behavior (Simpson et al., 2000), adults and children who practice geophagy (Vermeer and Frate, 1979), institutionalized children (Wong, 1988), and children with developmental delays (Danford, 1983), autism (Kinnell, 1985), or celiac disease (Korman, 1990). However, identifying specific soil-pica and geophagy populations remains difficult due to limited research on this topic. It has been estimated that 33% of children ingest more than 10 grams of soil 1 or 2 days a year (ATSDR, 2001). No information was located regarding the prevalence of geophagy behavior.

Because some soil and dust ingestion may be a result of hand-to-mouth behavior, soil properties may be important. For example, soil particle size, organic matter content, moisture content, and other soil properties may affect the adherence of soil to the skin. Soil particle sizes range from 50−2,000 μm for sand, 2−50 μm for silt, and are <2 μm for clay (USDA, 1999), while typical atmospheric dust particle sizes are in the range of 0.001−30 μm (Mody and Jakhete, 1987). Studies on particle size have indicated that finer soil particles (generally <63 μm in diameter) tend to be adhered more efficiently to human hands, whereas adhered soil fractions are independent of organic matter content or soil origin (Choate et al., 2006; Yamamoto et al., 2006). More large particle soil fractions have been shown to adhere to the skin for soils with higher moisture content (Choate et al., 2006).

In this handbook, soil, indoor settled dust and outdoor settled dust are defined generally as the following:

Soil. Particles of unconsolidated mineral and/or organic matter from the earth's surface that are located outdoors, or are used indoors to support plant growth. It includes particles that have settled onto outdoor objects and surfaces (outdoor settled dust).

Indoor Settled Dust. Particles in building interiors that have settled onto objects, surfaces, floors, and carpeting. These particles may include soil particles that have been tracked or blown into the indoor environment from outdoors as well as organic matter.

Outdoor Settled Dust. Particles that have settled onto outdoor objects and surfaces due to either wet or dry deposition. Note that it may not be possible to distinguish between soil and outdoor settled dust, since outdoor settled dust generally would be present on the uppermost surface layer of soil.

For the purposes of this handbook, soil ingestion includes both soil and outdoor settled dust, and dust ingestion includes indoor settled dust only.

There are several methodologies represented in the literature related to soil and dust ingestion. Two methodologies combine biomarker measurements with measurements of the biomarker substance's presence in environmental media. An additional methodology offers modeled estimates of soil/dust ingestion from activity pattern data from observational studies (e.g., videography) or from the responses to survey questionnaires about children's activities, behaviors, and locations.

The first of the biomarker methodologies measures quantities of specific elements present in feces, urine, food and medications, yard soil, house dust, and sometimes also community soil and dust, and combines this information using certain assumptions about the elements' behavior in the gastrointestinal tract to produce estimates of soil and dust quantities ingested (Davis et al., 1990). In this chapter, this methodology is referred to as the "tracer element" methodology. The second biomarker methodology compares results from a biokinetic model of lead exposure and uptake that predict blood lead levels, with biomarker measurements of lead in blood (Von Lindern et al., 2003). The model predictions are made using assumptions about ingested soil and dust quantities that are based, in part, on results from early versions of the first methodology. Therefore, the comparison with actual measured blood lead levels serves to confirm, to some extent, the assumptions about ingested soil and dust quantities used in the biokinetic model. In this chapter, this methodology is referred to as the "biokinetic model comparison" methodology. Lead isotope ratios have also been used as a biomarker to study sources of lead exposures in children. This technique involves measurements of different lead isotopes in blood and/or urine, food, water, and house dust and compares the ratio of different lead isotopes to infer sources of lead exposure that may include dust or other environmental exposures (Manton et al., 2000). However, application of lead isotope ratios to derive estimates of dust ingestion by children has not been attempted. Therefore, it is not discussed any further in this chapter.

The third, "activity pattern" methodology, combines information from hand-to-mouth and object-to-mouth behaviors with microenvironment data (i.e., time spent at different locations) to derive estimates of soil and dust ingestion. Behavioral information often comes from data obtained using videography techniques or from responses to survey questions obtained from adults, caregivers, and/or children. Surveys often include questions about hand-to-mouth and object-to-mouth behaviors, soil and dust ingestion behaviors, frequency, and sometimes quantity (Barltrop, 1966).

Although not directly evaluated in this chapter, a fourth methodology uses assumptions regarding ingested quantities of soil and dust that are based on a general knowledge of human behavior, and potentially supplemented or informed by data from other methodologies (Wong et al., 2000; Kissel et al., 1998; Hawley, 1985).

The recommendations for soil, dust, and soil + dust ingestion rates are provided in the next section, along with a summary of the confidence ratings for these recommendations. The recommended values are based on key studies identified by the U.S. Environmental Protection Agency (U.S. EPA) for this factor. Following the recommendations, a description of the three methodologies used to estimate soil and dust ingestion is provided, followed by a summary of key and relevant studies. Because strengths and limitations of each one of the key and relevant studies relate to the strengths and limitations inherent of the methodologies themselves, they are discussed at the end of the key and relevant studies.

5.2. RECOMMENDATIONS

The key studies described in Section 5.3 were used to recommend values for soil and dust ingestion for adults and children. Table 5-1 shows the central tendency recommendations for daily ingestion of soil, dust, or soil + dust, in mg/day. It also shows the high end recommendations for daily ingestion of soil, in mg/day. The high end recommendations are subdivided into a general population soil ingestion rate, an ingestion rate for "soil-pica," and an estimate for individuals who exhibit "geophagy." The soil pica and geophagy recommendations are likely to represent an acute high soil ingestion episode or behaviors at an unknown point on the high end of the distribution of soil ingestion. Published estimates from the key studies have been rounded to one significant figure.

The soil ingestion recommendations in Table 5-1 are intended to represent ingestion of a combination of soil and outdoor settled dust, without distinguishing between these two sources. The source of the soil in these recommendations could be outdoor soil, indoor containerized soil used to support growth of indoor plants, or a combination of both outdoor soil and containerized indoor soil. The inhalation and subsequent swallowing of soil particles is accounted for in these recommended values, therefore, this pathway does not need to be considered separately. These recommendations are called "soil." The dust ingestion recommendations in Table 5-1 include soil tracked into the indoor setting, indoor settled dust, and air-suspended particulate matter that is inhaled and swallowed. Central tendency "dust" recommendations are provided, in the event that assessors need recommendations for an indoor or inside a transportation vehicle scenario in which dust, but not outdoor soil, is the exposure medium of concern. The soil + dust recommendations would include soil, either from outdoor or containerized indoor sources, dust that is a combination of outdoor settled dust, indoor settled dust, and air-suspended particulate matter that is inhaled, subsequently trapped in mucous and moved from the respiratory system to the gastrointestinal tract, and a soil-origin material located on indoor floor surfaces that was tracked indoors by building occupants. Soil and dust recommendations exclude the soil or dust's moisture content. In other words, recommended values represent mass of ingested soil or dust that is represented on a dry-weight basis.

Studies estimating adult soil ingestion are extremely limited, and only two of these are considered to be key studies [i.e., Vermeer and Frate (1979); Davis and Mirick (2006)]. In the Davis and Mirick (2006) study, soil ingestion for adults and children in the same family was calculated using a mass-balance approach. The adult data were seen to be more variable than for the children in the study, possibly indicating an important occupational contribution of soil ingestion in some of the adults. For the aluminum and silicon tracers, soil ingestion rates ranged from 23−92 mg/day (mean), 0−23 mg/day (median), and 138−814 mg/day (maximum), with an overall mean value of 52 mg/day for the adults in the study. Based on this value, the recommended mean value from the Davis and Mirick (2006) study is estimated to be 50 mg/day for adult soil and dust ingestion (see Table 5-1). There are no available studies estimating the ingestion of dust by adults, therefore, the assumption used by U.S. EPA's Integrated Exposure and Uptake Biokinetic (IEUBK) model for lead in children (i.e., 45% soil, 55% dust contribution) was used to derive estimates for soil and dust using the soil + dust value derived from Davis and Mirick (2006). Rounded to one significant figure, these estimates are 20 mg/day and 30 mg/day for soil and dust respectively.

The key studies pre-dated the age groups recommended for children by U.S. EPA (2005) and were performed on groups of children of varying ages. As a result, central tendency recommendations can be used for the life stage categories of 6 to <12 months, 1 to <2 years, 2 to <3 years, 3 to <6 years, and part of the 6 to <11 years categories. Upper percentile recommendations can be used for the life stage categories of 1 to <2 years, 2 to <3 years, 3 to <6 years, 6 to <11 years, and part or all of the 11 to <16 years category.

The recommended central tendency soil + dust ingestion estimate for infants from 6 weeks up to their first birthday is 60 mg/day (Hogan et al., 1998; van Wijnen et al., 1990). If an estimate is needed for soil only, from soil derived from outdoor or indoor sources, or both outdoor and indoor sources, the recommendation is 30 mg/day (van Wijnen et al., 1990). If an estimate for indoor dust only is needed, that would include a certain quantity of tracked-in soil from outside, the recommendation is 30 mg/day (Hogan et al., 1998). This dust ingestion value is based on the 30 mg/day value for soil ingestion for this age group (van Wijnen et al., 1990), and the assumption that the soil and dust inhalation values will be comparable, as were the Hogan et al. (1998) values for the 1 to <6 year age group. The confidence rating for this recommendation is low due to the small numbers of study subjects in the IEUBK model study on which the recommendation is in part based and the inferences needed to develop a quantitative estimate. Examples of these inferences include: an assumption that the relative proportions of soil and dust ingested by 6 week to <12 month old children are the same as those ingested by older children [45% soil, 55% dust, based on U.S. EPA (1994a)], and the assumption that pre-natal or non-soil, non-dust sources of lead exposure do not dominate these children's blood lead levels.

When assessing risks for individuals who are not expected to exhibit soil-pica or geophagy behavior, the recommended central tendency soil + dust ingestion estimate is 100 mg/day for children ages 1 to <21 years (Hogan et al., 1998). If an estimate for soil only is needed, for exposure to soil such as manufactured topsoil or potted-plant soil that could occur in either an indoor or outdoor setting, or when the risk assessment is not considering children's ingestion of indoor dust (in an indoor setting) as well, the recommendation is 50 mg/day (Hogan et al., 1998). If an estimate for indoor dust only is needed, the recommendation is 60 mg/day (Hogan et al., 1998). Although these quantities add up to 110 mg/day, the sum is rounded to one significant figure. Although there were no tracer element studies or biokinetic model comparison studies performed for children 6 to <21 years, as a group, their mean or central tendency soil ingestion would not be zero. In the absence of data that can be used to develop specific central tendency soil and dust ingestion recommendations for children aged 6 to <11 years, 11 to <16 years and 16 to <21 years, U.S. EPA recommends using the same central tendency soil and dust ingestion rates that are recommended for children in the 1 to <6 year old age range.

No key studies are available estimating soil-pica behavior in children less than 12 months of age or in adults, therefore, no recommended values are provided for these age groups. The upper percentile recommendation for soil and dust ingestion among the general population of children 3 to <6 years old is 200 mg/day and it is based on the 95th percentile value obtained from modeling efforts from Özkaynak et al. (2011) and from 95th percentile estimates derived by Stanek and Calabrese (1995b). When assessing risks for children who may exhibit soil-pica behavior, or a group of children that includes individual children who may exhibit soil-pica behavior, the soil-pica ingestion estimate in the literature for children up to age 14 ranges from 400 to 41,000 mg/day (Stanek et al., 1998; Calabrese et al., 1997b; Calabrese et al., 1997a; Calabrese and Stanek, 1993; Calabrese et al., 1991; Barnes, 1990; Calabrese et al., 1989; Wong, 1988; Vermeer and Frate, 1979). Due to the definition of soil-pica used in this chapter, that sets a lower bound on the quantity referred to as "soil-pica" at 1,000 mg/day (ATSDR, 2001), and due to the significant number of observations in the U.S. tracer element studies that are at or exceed that quantity, the recommended soil-pica ingestion rate is 1,000 mg/day. It should be noted, however, that this value may be more appropriate for acute exposures. Currently, no data are available for soil-pica behavior for children ages 6 to <21 years. Because pica behavior may occur among some children ages ~1 to 21 years old (Hyman et al., 1990), it is prudent to assume that, for some children, soil-pica behavior may occur at any age up to 21 years.

The recommended geophagy soil estimate is 50,000 mg/day (50 grams) for both adults and children (Vermeer and Frate, 1979). It is important to note that this value may be more representative of acute exposures. Risk assessors should use this value for soil ingestion in areas where residents are known to exhibit geophagy behaviors.

Table 5-2 shows the confidence ratings for these recommendations. Section 5.4 gives a more detailed explanation of the basis for the confidence ratings.

An important factor to consider when using these recommendations is that they are limited to estimates of soil and dust quantities ingested. The scope of this chapter is limited to quantities of soil and dust taken into the gastrointestinal tract, and does not extend to issues regarding bioavailability of environmental contaminants present in that soil and dust. Information from other sources is needed to address bioavailability. In addition, as more information becomes available regarding gastrointestinal absorption of environmental contaminants, adjustments to the soil and dust ingestion exposure equations may need to be made, to better represent the direction of movement of those contaminants within the gastrointestinal tract.

To place these recommendations into context, it is useful to compare these soil ingestion rates to common measurements. The central tendency recommendation of 50 mg/day or 0.050 g/day, dry-weight basis, would be equivalent to approximately 1/6 of an aspirin tablet per day because the average aspirin tablet is approximately 325 mg. The 50 g/day ingestion rate recommended to represent geophagy behavior would be roughly equivalent to 150 aspirin tablets per day.

Table 5-1. Recommended Values for Daily Soil, Dust, and Soil + Dust Ingestion (mg/day)

	Soil[a]				Dust[b]		Soil + Dust	
		High End						
Age Group	General Population Central Tendency[c]	General Population Upper Percentile[d]	Soil-Pica[e]	Geophagy[f]	General Population Central Tendency[g]	General Population Upper Percentile[h]	General Population Central Tendency[c]	General Population Upper Percentile[h]
6 weeks to <1 year	30				30		60	
1 to <6 years	50		1,000	50,000	60		100[i]	
3 to <6 years		200				100		200
6 to <21 years	50		1,000	50,000	60		100[i]	
Adult	20[j]			50,000	30[j]		50	

a Includes soil and outdoor settled dust.
b Includes indoor settled dust only.
c Davis and Mirick (2006); Hogan et al. (1998); Davis et al. (1990); van Wïjnen et al. (1990); Calabrese and Stanek (1995).
d Özkaynak et al. (2011); Stanek and Calabrese (1995b); rounded to one significant figure.
e ATSDR (2001); Stanek et al. (1998); Calabrese et al. (1997b; 1997a; 1991; 1989); Calabrese and Stanek (1993); Barnes (1990); Wong (1988); Vermeer and Frate (1979).
f Vermeer and Frate (1979).
g Hogan et al. (1998).
h Özkaynak et al. (2011); rounded to one significant figure.
i Total soil and dust ingestion rate is 110 mg/day; rounded to one significant figure it is 100 mg/day.
j Estimates of soil and dust were derived from the soil + dust and assuming 45% soil and 55% dust.

Table 5-2. Confidence in Recommendations for Ingestion of Soil and Dust		
General Assessment Factors	Rationale	Rating
Soundness		Low
Adequacy of Approach	The methodologies have significant limitations. The studies did not capture all of the information needed (quantities ingested, frequency of high soil ingestion episodes, prevalence of high soil ingestion). Six of the 12 key studies were of census or randomized design. Sample selection may have introduced some bias in the results (i.e., children near smelter or Superfund sites, volunteers in nursery schools). The total number of adults and children in key studies were 122 and 1,203 (859 U.S. children, 292 Dutch, and 52 Jamaican children), respectively, while the target population currently numbers more than 74 million (U.S. Department of Commerce, 2008). Modeled estimates were based on 1,000 simulated individuals. The response rates for in-person interviews and telephone surveys were often not stated in published articles. Primary data were collected for 381 U.S. children and 292 Dutch children; secondary data for 478 U.S. children and 52 Jamaican children. Two key studies provided data for adults.	
Minimal (or defined) Bias	Numerous sources of measurement error exist in the tracer element studies. Biokinetic model comparison studies may contain less measurement error than tracer element studies. Survey response study may contain measurement error. Some input variables for the modeled estimates are uncertain.	
Applicability and Utility		Low
Exposure Factor of Interest	Eleven of the 12 key studies focused on the soil exposure factor, with no or less focus on the dust exposure factor. The biokinetic model comparison study did not focus exclusively on soil and dust exposure factors.	
Representativeness	The study samples may not be representative of the United States in terms of race, ethnicity, socioeconomics, and geographical location; studies focused on specific areas.	
Currency	Studies results are likely to represent current conditions.	
Data Collection Period	Tracer element studies' data collection periods may not represent long-term behaviors. Biokinetic model comparison and survey response studies do represent longer term behaviors. Data used in modeled simulation estimates may not represent long-term behaviors.	
Clarity and Completeness		Low
Accessibility	Observations for individual children are available for only three of the 12 key studies.	
Reproducibility	For the methodologies used by more than one research group, reproducible results were obtained in some instances. Some methodologies have been used by only one research group and have not been reproduced by others.	
Quality Assurance	For some studies, information on quality assurance/quality control was limited or absent.	
Variability and Uncertainty		Low
Variability in Population	Tracer element and activity pattern methodology studies characterized variability among study sample members; biokinetic model comparison and survey response studies did not. Day-to-day and seasonal variability was not very well characterized. Numerous factors that may influence variability have not been explored in detail.	
Minimal Uncertainty	Estimates are highly uncertain. Tracer element studies' design appears to introduce biases in the results. Modeled estimates may be sensitive to input variables.	
Evaluation and Review		Medium
Peer Review	All key studies appeared in peer-review journals.	
Number and Agreement of Studies	12 key studies. Some key studies are reanalysis of previously published data. Researchers using similar methodologies obtained generally similar results; somewhat general agreement between researchers using different methodologies.	
Overall Rating		**Low**

5.3. KEY AND RELEVANT STUDIES

The key tracer element, biokinetic model comparison, and survey response studies are summarized in the following sections. Certain studies were considered "key" and were used as a basis for developing the recommendations, using judgment about the study's design features, applicability, and utility of the data to U.S. soil and dust ingestion rates, clarity and completeness, and characterization of uncertainty and variability in ingestion estimates. Because the studies often were performed for reasons unrelated to developing soil and dust ingestion recommendations, their attributes that were characterized as "limitations" in this chapter might not be limitations when viewed in the context of the study's original purpose. However, when studies are used for developing a soil or dust ingestion recommendation, U.S. EPA has categorized some studies' design or implementation as preferable to others. In general, U.S. EPA chose studies designed either with a census or randomized sample approach over studies that used a convenience sample, or other non-randomized approach, as well as studies that more clearly explained various factors in the study's implementation that affect interpretation of the results. However, in some cases, studies that used a non-randomized design contain information that is useful for developing exposure factor recommendations (for example, if they are the only studies of children in a particular age category), and thus may have been designated as "key" studies. Other studies were considered "relevant" but not "key" because they provide useful information for evaluating the reasonableness of the data in the key studies, but in U.S. EPA's judgment they did not meet the same level of soundness, applicability and utility, clarity and completeness, and characterization of uncertainty and variability that the key studies did. In addition, studies that did not contain information that can be used to develop a specific recommendation for mg/day soil and dust ingestion were classified as relevant rather than key.

Some studies are re-analyses of previously published data. For this reason, the sections that follow are organized into key and relevant studies of primary analysis (that is, studies in which researchers have developed primary data pertaining to soil and dust ingestion) and key and relevant studies of secondary analysis (that is, studies in which researchers have interpreted previously published results, or data that were originally collected for a different purpose).

5.3.1. Methodologies Used in Key Studies

5.3.1.1. *Tracer Element Methodology*

The tracer element methodology attempts to quantify the amounts of soil ingested by analyzing samples of soil and dust from residences and/or children's play areas, and feces or urine. The soil, dust, fecal, and urine samples are analyzed for the presence and quantity of tracer elements—typically, aluminum, silicon, titanium, and other elements. A key underlying assumption is that these elements are not metabolized into other substances in the body or absorbed from the gastrointestinal tract in significant quantities, and thus their presence in feces and urine can be used to estimate the quantity of soil ingested by mouth. Although they are sometimes called mass balance studies, none of the studies attempt to quantify amounts excreted in perspiration, tears, glandular secretions, or shed skin, hair or finger- and toenails, nor do they account for tracer element exposure via the dermal or inhalation into the lung routes, and thus they are not a complete "mass balance" methodology. Early studies using this methodology did not always account for the contribution of tracer elements from non-soil substances (food, medications, and non-food sources such as toothpaste) that might be swallowed. U.S. studies using this methodology in or after the mid to late 1980s account for, or attempt to account for, tracer element contributions from these non-soil sources. Some study authors adjust their soil ingestion estimate results to account for the potential contribution of tracer elements found in household dust as well as soil.

The general algorithm that is used to calculate the quantity of soil or dust estimated to have been ingested is as follows: the quantity of a given tracer element, in milligrams, present in the feces and urine, minus the quantity of that tracer element, in milligrams, present in the food and medicine, the result of which is divided by the tracer element's soil or dust concentration, in milligrams of tracer per gram of soil or dust, to yield an estimate of ingested soil, in grams.

The U.S. tracer element researchers have all assumed a certain offset, or lag time between ingestion of food, medication, and soil, and the resulting fecal and urinary output. The lag times used are typically 24 or 28 hours; thus, these researchers subtract the previous day's food and medication tracer element quantity ingested from the current day's fecal and urinary tracer element quantity that was excreted. When compositing food, medication, fecal and urine samples across the entire study period, daily estimates can be obtained by dividing the total estimated soil ingestion by the number of days in which fecal and/or urine samples were collected. A variation of the algorithm that provides slightly higher estimates of soil ingestion is to divide the total estimated soil ingestion by the number of days on which feces were produced, which by definition would be equal to or less than the total number of days of the study period's fecal sample collection.

Substituting tracer element dust concentrations for tracer element soil concentrations yields a dust ingestion estimate. Because the actual non-food, non-medication quantity ingested is a combination of soil and dust, the unknown true soil and dust ingestion is likely to be somewhere between the estimates that are based on soil concentrations and estimates that are based on dust concentrations. Tracer element researchers have described ingestion estimates for soil that actually represent a combination of soil and dust, but were calculated based on tracer element concentrations in soil. Similarly, they have described ingestion estimates for dust that are actually for a combination of soil and dust, but were calculated based on tracer element concentrations in dust. Other variations on these general soil and dust ingestion algorithms have been published, in attempts to account for time spent indoors, time spent away from the house, etc. that could be expected to influence the relative proportion of soil versus dust.

Each individual's soil and dust ingestion can be represented as an unknown constant in a set of simultaneous equations of soil or dust ingestion represented by different tracer elements. To date, only two of the U.S. research teams (Barnes, 1990; Lásztity et al., 1989) have published estimates calculated for pairs of tracer elements using simultaneous equations.

The U.S. tracer element studies have been performed for only short-duration study periods, and only for 33 adults (Davis and Mirick, 2006) and 241 children [101 in Davis et al. (1990), 12 of whom were studied again in Davis and Mirick (2006); 64 in Calabrese et al. (1989) and Barnes (1990); 64 in Calabrese et al. (1997b); and 12 in Calabrese et al. (1997a)]. They provide information on quantities of soil and dust ingested for the studied groups for short time periods, but provide limited information on overall prevalence of soil ingestion by U.S. adults and children, and limited information on the frequency of higher soil ingestion episodes.

The tracer element studies appear to contain numerous sources of error that influence the estimates upward and downward. Sometimes the error sources cause individual soil or dust ingestion estimates to be negative, which is not physically possible. In some studies, for some of the tracers, so many individual "mass balance" soil ingestion estimates were negative that median or mean estimates based on that tracer were negative. For soil and dust ingestion estimates based on each particular tracer, or averaged across tracers, the net impact of these competing upward and downward sources of error is unclear.

5.3.1.2. *Biokinetic Model Comparison Methodology*

The Biokinetic Model Comparison methodology compares direct measurements of a biomarker, such as blood or urine levels of a toxicant, with predictions from a biokinetic model of oral, dermal and inhalation exposure routes with air, food, water, soil, and dust toxicant sources. An example is to compare measured children's blood lead levels with predictions from the IEUBK model. Where environmental contamination of lead in soil, dust, and drinking water has been measured and those measurements can be used as model inputs for the children in a specific community, the model's assumed soil and dust ingestion values can be confirmed or refuted by comparing the model's predictions of blood lead levels with those children's measured blood lead levels. It should be noted, however, that such confirmation of the predicted blood lead levels would be confirmation of the net impact of all model inputs, and not just soil and dust ingestions. Under the assumption that the actual measured blood lead levels of various groups of children studied have minimal error, and those measured blood lead levels roughly match biokinetic model predictions for those groups of children, then the model's default assumptions may be roughly accurate for the central tendency, or typical, children in an assessed group of children. The model's default assumptions likely are not as useful for predicting outcomes for highly exposed children.

5.3.1.3. *Activity Pattern Methodology*

The activity pattern methodology includes observational studies as well as surveys of adults, children's caretakers, or children themselves, via in-person or mailed questionnaires that ask about mouthing behavior and ingestion of various non-food items and time spent in various microenvironments. There are three general approaches to gather data on children's mouthing behavior: real-time hand recording, in which trained observers manually record information (Davis et al., 1995); video-transcription, in which trained videographers tape a child's activities and subsequently extract the pertinent data manually or with computer software (Black et al., 2005); and questionnaire, or survey response, techniques (Stanek et al., 1998).

The activity-pattern methodology combines information on hand-to-mouth and object-to-mouth activities (microactivities) and time spent at various locations (microenvironments) with assumptions about transfer parameters (e.g., soil-to-skin adherence, saliva removal efficiency) and other exposure factors (e.g., frequency of hand washing) to derive estimates of soil and dust ingestion. This methodology has been used in U.S. EPA's Stochastic Human Exposure and Dose Simulation (SHEDS) model. The SHEDS model is a probabilistic model that can simulate cumulative (multiple chemicals) or aggregate (single chemical) residential exposures for a population of interest over time via multiple routes of exposure for different types of chemicals and scenarios, including those involving soil ingestion (U.S. EPA, 2010).

One of the limitations of this approach includes the availability and quality of the input variables. Özkaynak et al. (2011) found that the model is most sensitive to dust loadings on carpets and hard floor surfaces, soil-to-skin adherence factors, hand mouthing frequency, and hand washing frequency (Ozkaynak et al., 2011).

5.3.2. Key Studies of Primary Analysis

5.3.2.1. *Vermeer and Frate (1979)—Geophagia in Rural Mississippi: Environmental and Cultural Contexts and Nutritional Implications*

Vermeer and Frate (1979) performed a survey response study in Holmes County, Mississippi in the 1970s (date unspecified). Questions about geophagy (defined as regular consumption of clay over a period of weeks) were asked of household members (N = 229 in 50 households; 56 were women, 33 were men, and 140 were children or adolescents) of a subset of a random sample of nutrition survey respondents. Caregiver responses to questions about 115 children under 13 indicate that geophagy was likely to be practiced by a minimum of 18 (16%) of these children; however, 16 of these 18 children were 1 to 4 years old, and only 2 of the 18 were older than 4 years. Of the 56 women, 32 (57%) reported eating clay. There was no reported geophagy among 33 men or 25 adolescent study subjects questioned.

In a separately administered survey, geophagy and pica data were obtained from 142 pregnant women over a period of 10 months. Geophagy was reported by 40 of these women (28%), and an additional 27 respondents (19%) reported other pica behavior, including the consumption of laundry starch, dry powdered milk, and baking soda.

The average daily amount of clay consumed was reported to be about 50 grams, for the adult and child respondents who acknowledged practicing geophagy. Quantities were usually described as either portions or multiples of the amount that could be held in a single, cupped hand. Clays for consumption were generally obtained from the B soil horizon, or subsoil rather than an uppermost layer, at a depth of 50 to 130 centimeters.

5.3.2.2. *Calabrese et al. (1989)—How Much Soil Do Young Children Ingest: An Epidemiologic Study/Barnes (1990)—Childhood Soil Ingestion: How Much Dirt Do Kids Eat?/Calabrese et al. (1991)—Evidence of Soil-Pica Behavior and Quantification of Soil Ingested*

Calabrese et al. (1989) and Barnes (1990) studied soil ingestion among children using eight tracer elements—aluminum, barium, manganese, silicon, titanium, vanadium, yttrium, and zirconium. A non-random sample of 30 male and 34 female 1, 2, and 3-year-olds from the greater Amherst, Massachusetts area were studied, presumably in 1987. The children were predominantly from two-parent households where the parents were highly educated. The study was conducted over a period of 8 days spread over 2 weeks. During each week, duplicate samples of food, beverages, medicines, and vitamins were collected on Monday through Wednesday, while excreta, excluding wipes and toilet paper, were collected for four 24-hour cycles running from Monday/Tuesday through Thursday/Friday. Soil and dust samples were also collected from the child’s home and play area. Study participants were supplied with toothpaste, baby cornstarch, diaper rash cream, and soap with low levels of most of the tracer elements.

Table 5-3 shows the published mean soil ingestion estimates ranging from −294 mg/day based on manganese to 459 mg/day based on vanadium, median soil ingestion estimates ranging from −261 mg/day based on manganese to 96 mg/day based on vanadium, and 95th percentile estimates ranged from 106 mg/day based on yttrium to 1,903 mg/day based on vanadium. Maximum daily soil ingestion estimates ranged from 1,391 mg/day based on zirconium to 7,281 mg/day based on manganese. Dust ingestions calculated using tracer concentrations in dust were often, but not always, higher than soil ingestions calculated using tracer concentrations in soil.

Data for the uppermost 23 subject-weeks (the highest soil ingestion estimates, averaged over the 4 days of excreta collection during each of the 2 weeks) were published in Calabrese et al. (1991). One child's soil-pica behavior was estimated in Barnes (1990) using both the subtraction/division algorithm and the simultaneous equations method. On two particular days during the second week of the study period, the child's aluminum-based soil ingestion estimates were 19 g/day (18,700 mg/day) and 36 g/day (35,600 mg/day), silicon-based soil ingestion estimates were 20 g/day (20,000 mg/day) and 24 g/day (24,000), and simultaneous-equation soil ingestion estimates were 20 g/day (20,100 mg/day) and 23 g/day (23,100 mg/day) (Barnes, 1990). By tracer, averaged across the entire week, this child's estimates ranged from approximately 10 to 14 g/day during the second week of observation [Calabrese et al. (1991), shown in Table 5-4], and averaged 6 g/day across the entire study period. Additional information about this child's apparent ingestion of soil versus dust during the study period was published in Calabrese and Stanek (1992b).

5.3.2.3. *Van Wïjnen et al. (1990)—Estimated Soil Ingestion by Children*

In a tracer element study by van Wïjnen et al. (1990), soil ingestion among Dutch children ranging in age from 1 to 5 years was evaluated using a tracer element methodology. Van Wïjnen et al. (1990) measured three tracers (titanium, aluminum, and acid insoluble residue [AIR]) in soil and feces. The authors estimated soil ingestion based on an assumption called the Limiting Tracer Method (LTM), which assumed that soil ingestion could not be higher than the lowest value of the three tracers. LTM values represented soil ingestion estimates that were not corrected for dietary intake.

An average daily feces dry weight of 15 grams was assumed. A total of 292 children attending daycare centers were studied during the first of two sampling periods and 187 children were studied in the second sampling period; 162 of these children were studied during both periods (i.e., at the beginning and near the end of the summer of 1986). A total of 78 children were studied at campgrounds. The authors reported geometric mean LTM values because soil ingestion rates were found to be skewed and the log-transformed data were approximately normally distributed. Geometric mean LTM values were estimated to be 111 mg/day for children in daycare centers and 174 mg/day for children vacationing at campgrounds (see Table 5-5). For the 162 daycare center children studied during both sampling periods the arithmetic mean LTM was 162 mg/day, and the median was 114 mg/day.

Fifteen hospitalized children were studied and used as a control group. These children's LTM soil ingestion estimates were 74 (geometric mean), 93 (mean), and 110 (median) mg/day. The authors assumed the hospitalized children's soil ingestion estimates represented dietary intake of tracer elements, and used rounded 95% confidence limits on the arithmetic mean, 70 to 120 mg/day, to correct the daycare and campground children's LTM estimates for dietary intake of tracers. Corrected soil ingestion rates were 69 mg/day (162 mg/day minus 93 mg/day) for daycare children and 120 mg/day (213 mg/day minus 93 mg/day) for campers. Corrected geometric mean soil ingestion was estimated to range from 0 to 90 mg/day, with a 90th percentile value of up to 190 mg/day for the various age categories within the daycare group and 30 to 200 mg/day, with a 90th percentile value of up to 300 mg/day for the various age categories within the camping group.

AIR was the limiting tracer in about 80%of the samples. Among children attending daycare centers, soil ingestion was also found to be higher when the weather was good (i.e., <2 days/week precipitation) than when the weather was bad (i.e., >4 days/week precipitation (see Table 5-6).

5.3.2.4. *Davis et al. (1990)—Quantitative Estimates of Soil Ingestion in Normal Children Between the Ages of 2 and 7 Years: Population-Based Estimates Using Aluminum, Silicon, and Titanium as Soil Tracer Elements*

Davis et al. (1990) used a tracer element technique to estimate soil ingestion among children. In this study, 104 children between the ages of 2 and 7 years were randomly selected from a three-city area in southeastern Washington State. Soil and dust ingestion was evaluated by analyzing soil and house dust, feces, urine, and duplicate food, dietary supplement, medication and mouthwash samples for aluminum, silicon, and titanium. Data were collected for 101 of the 104 children during July, August, or September, 1987. In each family, data were collected over a 7-day period, with 4 days of excreta sample collection. Participants were supplied with toothpaste with known tracer element content. In addition, information on dietary habits and demographics was collected in an attempt to identify behavioral and demographic characteristics that influence soil ingestion rates among children. The amount of soil ingested on a daily basis was estimated using Equation 5-1:

$$S_{i,e} = \frac{(((DW_f + DW_p) \times E_f) + 2E_u) - (DW_{fd} \times E_{fd})}{E_{soil}} \quad \text{(Eqn. 5-1)}$$

where:

$S_{i,e}$	=soil ingested for child *i* based on tracer *e* (grams);
DW_f	=feces dry weight (grams);
DW_p	=feces dry weight on toilet paper (grams);
E_f	=tracer concentration in feces (µg/g);
E_u	=tracer amount in urine (µg);
DW_{fd}	=food dry weight (grams);
E_{fd}	=tracer concentration in food (µg/g); and
E_{soil}	=tracer concentration in soil (µg/g).

The soil ingestion rates were corrected by adding the amount of tracer in vitamins and medications to the amount of tracer in food, and adjusting the food, fecal and urine sample weights to account for missing samples. Food, fecal and urine samples were composited over a 4-day period, and estimates for daily soil ingestion were obtained by dividing the 4-day composited tracer quantities by 4.

Soil ingestion rates were highly variable, especially those based on titanium. Mean daily soil ingestion estimates were 38.9 mg/day for aluminum, 82.4 mg/day for silicon and 245.5 mg/day for titanium (see Table 5-7). Median values were 25 mg/day for aluminum, 59 mg/day for silicon, and 81 mg/day for titanium. The investigators also evaluated the extent to which differences in tracer concentrations in house dust and yard soil impacted estimated soil ingestion rates. The value used in the denominator of the soil ingestion estimate equation was recalculated to represent a weighted average of the tracer concentration in yard soil and house dust based on the proportion of time the child spent indoors and outdoors, using an assumption that the likelihood of ingesting soil outdoors was the same as that of ingesting dust indoors. The adjusted mean soil/dust ingestion rates were 64.5 mg/day for aluminum, 160.0 mg/day for silicon, and 268.4 mg/day for titanium. Adjusted median soil/dust ingestion rates were: 51.8 mg/day for aluminum, 112.4 mg/day for silicon, and 116.6 mg/day for titanium. The authors investigated whether nine behavioral and demographic factors could be used to predict soil ingestion, and found family income less than $15,000/year and swallowing toothpaste to be significant predictors with silicon-based estimates; residing in one of the three cities to be a significant predictor with aluminum-based estimates, and washing the face before eating significant for titanium-based estimates.

5.3.2.5. *Calabrese et al. (1997b)—Soil Ingestion Estimates for Children Residing on a Superfund Site*

Calabrese et al. (1997b) estimated soil ingestion rates for children residing on a Superfund site using a methodology in which eight tracer elements were analyzed. The methodology used in this study is similar to that employed in Calabrese et al. (1989), except that rather than using barium, manganese, and vanadium as three of the eight tracers, the researchers replaced them with cerium, lanthanum, and neodymium. A total of 64 children ages 1−3 years (36 male, 28 female) were selected for this study of the Anaconda, Montana area. The study was conducted for seven consecutive days during September or September and October, apparently in 1992, shortly after soil was removed and replaced in some residential yards in the area. Duplicate samples of meals, beverages, and over-the-counter medicines and vitamins were collected over the 7 day period, along with fecal samples. In addition, soil and dust samples were collected from the children's home and play areas. Toothpaste containing non-detectable levels of the tracer elements, with the exception of silica, was provided to all of the children. Infants were provided with baby cornstarch, diaper rash cream, and soap, which were found to contain low levels of tracer elements.

Because of the high degree of intertracer variability, Calabrese et al. (1997b) also derived estimates based on the "Best Tracer Methodology" (BTM). This BTM uses food/soil tracer concentration ratios in order to correct for errors caused by misalignment of tracer input and outputs, ingestion of non-food sources, and non-soil sources (Stanek and Calabrese, 1995b). A low food/soil ratio is desired because it minimizes transit time errors. The BTM did not use the results from Ce, La, and Nd despite these tracers having low food/soil ratios because the soil concentrations for these elements were found to be affected by particle size and more susceptible to source errors. Calabrese et al. (1997b) noted that estimates based on Al, Si, and Y in this study may result in lower soil ingestion estimates than the true value because the apparent residual negative errors found for these three tracers for a large majority of subjects. It was noted that soil ingestion estimates for this population may be lower than estimates found by previous studies in the literature because of families' awareness of contamination from the Superfund site, which may have resulted in altered behavior.

Soil ingestion estimates were also examined based on various demographic characteristics. There were no statistically significant differences in soil ingestion based on age, sex, birth order, or house yard characteristics (Calabrese et al., 1997b). Although not statistically significant, soil ingestion rates were generally higher for females, children with lower birth number, children with parents employed as laborers, or in service profession, homemakers, or unemployed and for children with pets (Calabrese et al., 1997b).

Table 5-8 shows the estimated soil and dust ingestion by each tracer element and by the BTM. Based on the BTM, the mean soil and dust ingestion rates were 65.5 mg/day and 127.2 mg/day, respectively.

5.3.2.6. *Stanek et al. (1998)—Prevalence of Soil Mouthing/Ingestion Among Healthy Children Aged One to Six/Calabrese et al. (1997a)—Soil Ingestion Rates in Children Identified by Parental Observation as Likely High Soil Ingesters*

Stanek et al. (1998) conducted a survey response study using in-person interviews of parents of children attending well visits at three western Massachusetts medical clinics in August, September, and October of 1992. Of 528 children ages 1 to 7 with completed interviews, parents reported daily mouthing or ingestion of sand and stones in 6%, daily mouthing or ingestion of soil and dirt in 4%, and daily mouthing or ingestion of dust, lint and dustballs in 1%. Parents reported more than weekly mouthing or ingestion of sand and stones in 16%, more than weekly mouthing or ingestion of soil and dirt in 10%, and more than weekly mouthing or ingestion of dust, lint and dustballs in 3%. Parents reported more than monthly mouthing or ingestion of sand and stones in 27%, more than monthly mouthing or ingestion of soil and dirt in 18%, and more than monthly mouthing or ingestion of dust, lint, and dustballs in 6%.

Calabrese and colleagues performed a follow-up tracer element study (Calabrese et al., 1997a) for a subset ($N = 12$) of the Stanek et al. (1998) children whose caregivers had reported daily sand/soil ingestion ($N = 17$). The time frame of the follow-up tracer study relative to the original survey response study was not stated; the study duration was 7 days. Of the 12 children in Calabrese et al. (1997a), one exhibited behavior that the authors believed was clearly soil pica; Table 5-9 shows estimated soil ingestion rates for this child during the study period. Estimates ranged from –10 mg/day to 7,253 mg/day depending on the tracer. Table 5-10 presents the estimated average daily soil ingestion estimates for the 12 children studied. Estimates calculated based on soil tracer element concentrations only ranged from –15 to +1,783 mg/day based on aluminum, −46 to +931 mg/day based on silicon, and –47 to +3,581 mg/day based on titanium. Estimated average daily dust ingestion estimates ranged from −39 to +2,652 mg/day based on aluminum, –351 to +3,145 mg/day based on silicon, and –98 to +3,632 mg/day based on titanium. Calabrese et al. (1997a) question the validity of retrospective caregiver reports of soil pica on the basis of the tracer element results.

5.3.2.7. *Davis and Mirick (2006)—Soil Ingestion in Children and Adults in the Same Family*

Davis and Mirick (2006) calculated soil ingestion for children and adults in the same family using a tracer element approach. Data were collected in 1988, one year after the Davis et al. (1990) study was conducted. Samples were collected and prepared for laboratory analysis and then stored for a 2-year period prior to tracer element quantification with laboratory analysis. Analytical recovery values for spiked samples were within the quality control limits of ±25%. The 20 families in this study were a non-random subset of the 104 families who participated in the soil ingestion study by Davis et al. (1990). Data collection issues resulted in sufficiently complete data for only 19 of the 20 families consisting of a child participant from the Davis et al. (1990) study ages 3 to 7, inclusive, and a female and male parent or guardian living in the same house. Duplicate samples of all food and medication items consumed, and all feces excreted, were collected for 11 consecutive days. Urine samples were collected twice daily for 9 of the 11 days; for the remaining 2 days, attempts were made to collect full 24-hour urine specimens. Soil and house dust samples were also collected. Only 12 children had sufficiently complete data for use in the soil and dust ingestion estimates.

Tracer elements for this study included aluminum, silicon, and titanium. Toothpaste was supplied for use by study participants. In addition, parents completed a daily diary of activities for themselves and the participant child for 4 consecutive days during the study period.

Table 5-11 shows soil ingestion rates for all three family member participants. The mean and median estimates for children for all three tracers ranged from 36.7 to 206.9 mg/day and 26.4 to 46.7 mg/day, respectively, and fall within the range of those reported by Davis et al. (1990). Adult soil ingestion estimates ranged from 23.2 to 624.9 mg/day for mean values and from 0 to 259.5 mg/day for median values. Adult soil ingestion estimates were more variable than those of children in the study regardless of the tracer. The authors believed that this higher variability may have indicated an important occupational contribution of soil ingestion in some, but not all, of the adults. Similar to previous studies, the soil ingestion estimates were the highest for titanium. Although toothpaste is a known source of titanium, the titanium content of the toothpaste used by study participants was not determined.

Only three of a number of behaviors examined for their relationship to soil ingestion were found to be associated with increased soil ingestion in this study:

- reported eating of dirt (for children);
- occupational contact with soil (for adults); and
- hand washing before meals (for both children and adults).

Several typical childhood behaviors, however, including thumb-sucking, furniture licking, and carrying around a blanket or toy were not associated with increased soil ingestion for the participating children. Among both parents and children, neither nail-biting nor eating unwashed fruits or vegetables was correlated with increased soil ingestion. However, because the study design required an equal amount of any food consumed to be included in the sample for analysis, eating unwashed fruits or vegetables would not have contributed to an increase in soil ingestion. Although eating unwashed fruits or vegetables was not associated with soil ingestion in either children or adults in this study, the authors noted that it is a behavior that could lead to soil ingestion. When investigating correlations within the same family, a child's soil ingestion was not found to be associated with either parent's soil ingestion, nor did the mother and father's soil ingestion appear to be correlated.

5.3.3. Key Studies of Secondary Analysis

5.3.3.1. *Wong (1988)—The Role of Environmental and Host Behavioral Factors in Determining Exposure to Infection With Ascaris lumbricoides and Trichuris Trichiura/Calabrese and Stanek (1993)—Soil Pica: Not a Rare Event*

Calabrese and Stanek (1993) reviewed a tracer element study that was conducted by Wong (1988) to estimate the amount of soil ingested by two groups of children. Wong (1988) studied a total of 52 children in two government institutions in Jamaica. The younger group included 24 children with an average age of 3.1 years (range of 0.3 to 7.5 years). The older group included 28 children with an average age of 7.2 years (range of 1.8 to 14 years). One fecal sample was collected each month from each subject over the 4-month study period. The amount of silicon in dry feces was measured to estimate soil ingestion.

An unspecified number of daily fecal samples were collected from a hospital control group of 30 children with an average age of 4.8 years (range of 0.3 to 12 years). Dry feces were observed to contain 1.45% silicon, or 14.5 mg Si per gram of dry feces. This quantity was used to correct measured fecal silicon from dietary sources. Fecal silicon quantities greater than 1.45% in the 52 studied children were interpreted as originating from soil ingestion.

For the 28 children in the older group, soil ingestion was estimated to be 58 mg/day, based on the mean minus one outlier, and 1,520 mg/day, based on the mean of all the children. The outlier was a child with an estimated average soil ingestion rate of 41 g/day over the 4 months.

Estimates of soil ingestion were higher in the younger group of 24 children. The mean soil ingestion of all the children was 470 ± 370 mg/day. Due to some sample losses, of the 24 children studied, only 15 had samples for each of the 4 months of the study. Over the entire 4-month study period, 9 of 84 samples (or 10.5%) yielded soil ingestion estimates in excess of 1 g/day.

Of the 52 children studied, 6 had one-day estimates of more than 1,000 mg/day. Table 5-12 shows the estimated soil ingestion for these six children. The article describes 5 of 24 (or 20.8%) in the younger group of children as having a >1,000 mg/day estimate on at least one of the four study days; in the older group one child is described in this manner. A high degree of daily variability in soil ingestion was observed among these six children; three showed soil-pica behavior on 2, 3, and 4 days, respectively, with the most consistent (4 out of

4 days) soil-pica child having the highest estimated soil ingestion, 3.8 to 60.7 g/day.

5.3.3.2. *Calabrese and Stanek (1995)—Resolving Intertracer Inconsistencies in Soil Ingestion Estimation*

Calabrese and Stanek (1995) explored sources and magnitude of positive and negative errors in soil ingestion estimates for children on a subject-week and trace element basis. Calabrese and Stanek (1995) identified possible sources of positive errors as follows:

- Ingestion of high levels of tracers before the start of the study and low ingestion during the study period; and
- Ingestion of element tracers from a non-food or non-soil source during the study period.

Possible sources of negative bias were identified as follows:

- Ingestion of tracers in food that are not captured in the fecal sample either due to slow lag time or not having a fecal sample available on the final study day; and
- Sample measurement errors that result in diminished detection of fecal tracers, but not in soil tracer levels.

The authors developed an approach that attempted to reduce the magnitude of error in the individual trace element ingestion estimates. Results from a previous study conducted by Calabrese et al. (1989) were used to quantify these errors based on the following criteria: (1) a lag period of 28 hours was assumed for the passage of tracers ingested in food to the feces (this value was applied to all subject-day estimates); (2) a daily soil ingestion rate was estimated for each tracer for each 24-hour day a fecal sample was obtained; (3) the median tracer-based soil ingestion rate for each subject-day was determined; and (4) negative errors due to missing fecal samples at the end of the study period were also determined. Also, upper- and lower-bound estimates were determined based on criteria formed using an assumption of the magnitude of the relative standard deviation presented in another study conducted by Stanek and Calabrese (1995a). Daily soil ingestion rates for tracers that fell beyond the upper and lower ranges were excluded from subsequent calculations, and the median soil ingestion rates of the remaining tracer elements were considered the best estimate for that particular day. The magnitude of positive or negative error for a specific tracer per day was derived by determining the difference between the value for the tracer and the median value.

Table 5-13 presents the estimated magnitude of positive and negative error for six tracer elements in the children's study [conducted by Calabrese et al. (1989)]. The original non-negative mean soil ingestion rates (see Table 5-3) ranged from a low of 21 mg/day based on zirconium to a high of 459 mg/day based on vanadium. The adjusted mean soil ingestion rate after correcting for negative and positive errors ranged from 97 mg/day based on yttrium to 208 mg/day based on titanium. Calabrese and Stanek (1995) concluded that correcting for errors at the individual level for each tracer element provides more reliable estimates of soil ingestion.

5.3.3.3. *Stanek and Calabrese (1995b)—Soil Ingestion Estimates for Use in Site Evaluations Based on the Best Tracer Method*

Stanek and Calabrese (1995b) recalculated soil ingestion rates for adults and children from two previous studies, using data for eight tracers from Calabrese et al. (1989) and three tracers from Davis et al. (1990). Recalculations were performed using the BTM. This method selected the “best” tracer(s), by dividing the total amount of tracer in a particular child’s duplicate food sample by tracer concentration in that child’s soil sample to yield a food/soil (F/S) ratio. The F/S ratio was small when the tracer concentration in food was low compared to the tracer concentration in soil. Small F/S ratios were desirable because they lessened the impact of transit time error (the error that occurs when fecal output does not reflect food ingestion, due to fluctuation in gastrointestinal transit time) in the soil ingestion calculation.

For adults, Stanek and Calabrese (1995b) used data for eight tracers from the Calabrese et al. (1989) study to estimate soil ingestion by the BTM. The lowest F/S ratios were Zr and Al and the element with the highest F/S ratio was Mn. For soil ingestion estimates based on the median of the lowest four F/S ratios, the tracers contributing most often to the soil ingestion estimates were Al, Si, Ti, Y, V, and Zr. Using the median of the soil ingestion rates based on the best four tracer elements, the average adult soil ingestion rate was estimated to be 64 mg/day with a median of 87 mg/day. The 95th percentile soil ingestion estimate was 142 mg/day. These estimates are based on 18 subject weeks for the six adult volunteers described in Calabrese et al. (1989).

The BTM used a ranking scheme of F/S ratios to determine the best tracers for use in the ingestion rate calculation. To reduce the impact of biases that may occur as a result of sources of fecal tracers other than food or soil, the median of soil ingestion estimates based on the four lowest F/S ratios was used to represent soil ingestion.

Using the lowest four F/S ratios for each individual, calculated on a per-week ("subject-week") basis, the median of the soil ingestion estimates from the Calabrese et al. (1989) study most often included aluminum, silicon, titanium, yttrium, and zirconium. Based on the median of soil ingestion estimates from the best four tracers, the mean soil ingestion rate for children was 132 mg/day and the median was 33 mg/day. The 95th percentile value was 154 mg/day. For the 101 children in the Davis et al. (1990) study, the mean soil ingestion rate was 69 mg/day and the median soil ingestion rate was 44 mg/day. The 95th percentile estimate was 246 mg/day. These data are based on the three tracers (i.e., aluminum, silicon, and titanium) from the Davis et al. (1990) study. When the results for the 128 subject-weeks in Calabrese et al. (1989) and 101 children in Davis et al. (1990) were combined, soil ingestion for children was estimated to be 104 mg/day (mean); 37 mg/day (median); and 217 mg/day (95th percentile), using the BTM.

5.3.3.4. *Hogan et al. (1998)—Integrated Exposure Uptake Biokinetic Model for Lead in Children: Empirical Comparisons With Epidemiologic Data*

Hogan et al. (1998) used the biokinetic model comparison methodology to review the measured blood lead levels of 478 children. These children were a subset of the entire population of children living in three historic lead smelting communities (Palmerton, Pennsylvania; Madison County, Illinois; and southeastern Kansas/southwestern Missouri), whose environmental lead exposures (soil and dust lead levels) had been studied as part of public health evaluations in these communities. The study populations were, in general, random samples of children 6 months to 7 years of age. Children who had lived in their residence for less than 3 months or those reported by their parents to be away from home more than 10 hours per week (>20 hours/week for the Pennsylvania data set) were excluded due to lack of information regarding lead exposure at the secondary location. The nature of the soil and dust exposures for the residential study population were typical, with the sample size considered sufficiently large to ensure that a wide enough range of children's behavior would be spanned by the data. Comparisons were made for a number of exposure factors, including age, location, time spent away from home, time spent outside, and whether or not children took food outside to eat.

The IEUBK model is a biokinetic model for predicting children's blood lead levels that uses measurements of lead content in house dust, soil, drinking water, food, and air, and child-specific estimates of intake for each exposure medium (dust, soil, drinking water, food and air). Model users can also use default assumptions for the lead contents and intake rates for each exposure medium when they do not have specific information for each child.

Hogan et al. (1998) compared children's measured blood lead levels with biokinetic model predictions (IEUBK version 0.99d) of blood lead levels, using the children's measured drinking water, soil, and dust lead contamination levels together with default IEUBK model inputs for soil and dust ingestion, relative proportions of soil and dust ingestion, lead bioavailability from soil and dust, and other model parameters. Thus, the default soil and dust ingestion rates in the model, and other default assumptions in the model, were tested by comparing measured blood lead levels with the model's predictions for those children's blood lead levels. Most IEUBK model kinetic and intake parameters were drawn independently from published literature (White et al., 1998; U.S. EPA, 1994b). Elimination parameters in particular had relatively less literature to draw upon (few data in children) and were fixed through a calibration exercise using a data set with children's blood lead levels paired with measured environmental lead exposures in and around their homes, while holding the other model parameters constant.

For Palmerton, Pennsylvania ($N = 34$), the community-wide geometric mean measured blood lead levels (6.8 µg/dL) were slightly over-predicted by the model (7.5 µg/dL); for southeastern Kansas/southwestern Missouri ($N = 111$), the blood lead levels (5.2 µg/dL) were slightly under-predicted (4.6 µg/dL), and for Madison County, Illinois ($N = 333$), the geometric mean measured blood lead levels matched the model predictions (5.9 µg/dL measured and predicted), with very slight differences in the 95% confidence interval. Although there may be uncertainty in these estimates, these results suggest that the default soil and dust ingestion rates used in this version of the IEUBK model (approximately 50 mg/day soil and 60 mg/day dust for a total soil + dust ingestion of 110 mg/day, averaged over children ages 1 through 6) may be roughly accurate in representing the central tendency soil and dust ingestion rates of residence-dwelling children in the three locations studied.

5.3.3.5. *Özkaynak et al. (2011)—Modeled Estimates of Soil and Dust Ingestion Rates for Children*

Özkaynak et al. (2011) developed soil and dust ingestion rates for children 3 to <6 years of age using U.S. EPA's SHEDS model for multimedia pollutants (SHEDS-Multimedia). The authors had two main objectives for this research: (1) to demonstrate an application of the SHEDS model while identifying and quantifying the key factors contributing to the predicted variability and uncertainty in the soil and dust ingestion exposure estimates, and (2) to compare the modeled results to existing tracer-element field measurements. The SHEDS model is a physically based probabilistic exposure model, which combines diary information on sequential time spent in different locations and activities drawn from U.S. EPA's Consolidated Human Activity Database (CHAD), with micro-activity data (e.g., hand-to-mouth frequency, hand-to-surface frequency), surface/object soil or dust loadings, and other exposure factors (e.g., soil-to-skin adherence, saliva removal efficiency). The SHEDS model generates simulated individuals, who are then followed through time, generally up to one year. The model computes changes to their exposure at the diary event level.

For this study, an indirect modeling approach was used, in which soil and dust were assumed to first adhere to the hands, and remain until washed off or ingested by mouthing. The object-to-mouth pathway for soil/dust ingestion was also addressed. For this application of the SHEDS model, however, other avenues of soil/dust ingestion were not considered. Outdoor matter was designated as "soil" and indoor matter as "dust." Estimates for the distributions of exposure factors such as activity, time outdoors, environmental concentrations, soil-skin and dust-skin transfer, hand washing frequency and efficiency, hand-mouthing frequency, area of object or hand mouthed, mouthing removal rates, and other variables were obtained from the literature. These input variables were used in this SHEDS model application to generate estimates of soil and dust ingestion rates for a simulated population of 1,000. Both sensitivity and uncertainty analyses were conducted. Based on the sensitivity analysis, the model results are the most sensitive to dust loadings on carpet and hard floor surfaces; soil-skin adherence factor; hand mouthing frequency, and; mean number of hand washes per day. Based on 200 uncertainty simulations that were conducted, the modeling uncertainties were seen to be asymmetrically distributed around the 50^{th} (median) or the central variability distribution.

Table 5-14 shows the predicted soil- and dust-ingestion rates. Mean total soil and dust ingestion was predicted to be 68 mg/day, with approximately 60% originating from soil ingestion, 30% from dust on hands, and 10% from dust on objects. Hand-to-mouth soil and dust ingestion was found to be the most important pathway, followed by hand-to-mouth dust ingestion, then object-to-mouth dust ingestion. The authors noted that these modeled estimates were found to be consistent with other soil/dust ingestion values in the literature, but slightly lower than the central tendency value of 100 mg/day recommended in U.S. EPA's *Child-Specific Exposure Factors Handbook* (U.S. EPA, 2008).

The advantages of this study include the fact that the SHEDS methodology can be applied to specific study populations of interest, a wide range of input parameters can be applied, and a full range of distributions can be generated. The primary limitation of this study is the lack of data for some of the input variables. Data needs include additional information on the activities and environments of children in younger age groups, including children with high hand-to-mouth, object-to-mouth, and pica behaviors, and information on skin adherence and dust loadings on indoor objects and floors. In addition, other age groups of interest were not included because of lack of data for some of the input variables.

5.3.4. Relevant Studies of Primary Analysis

The following studies are classified as relevant rather than key. The tracer element studies described in this section are not designated as key because the methodology to account for non-soil tracer exposures was not as well-developed as the methodology in the U.S. tracer element studies described in Sections 5.3.2 and 5.3.3, or because they do not provide a quantitative estimate of soil ingestion. However, the method of Clausing et al. (1987) was used in developing biokinetic model default soil and dust ingestion rates (U.S. EPA, 1994a) used in the Hogan et al. (1998) study, which was designated as key. In the survey response studies, in most cases the studies were of a non-randomized design, insufficient information was provided to determine important details regarding study design, or no data were provided to allow quantitative estimates of soil and/or dust ingestion rates.

5.3.4.1. *Dickins and Ford (1942)—Geophagy (Dirt Eating) Among Mississippi Negro School Children*

Dickens and Ford conducted a survey response study of rural Black school children (4th grade and above) in Oktibbeha County, Mississippi in September 1941. A total of 52 of 207 children (18 of 69 boys and 34 of 138 girls) studied gave positive responses to questions administered in a test-taking format regarding having eaten dirt in the previous 10 to 16 days. The authors stated that the study sample likely was more representative of the higher socioeconomic levels in the community, because older children from lower socioeconomic levels sometimes left school in order to work, and because children in the lower grades, who were more socioeconomically representative of the overall community, were excluded from the study. Clay was identified as the predominant type of soil eaten.

5.3.4.2. *Ferguson and Keaton (1950)—Studies of the Diets of Pregnant Women in Mississippi: II Diet Patterns*

Ferguson and Keaton (1950) conducted a survey response study of a group of 361 pregnant women receiving health care at the Mississippi State Board of Health, who were interviewed regarding their diet, including the consumption of clay or starch. All of the women were from the lowest economic and educational level in the area, and 92% were Black. Of the Black women, 27% reported clay-eating and 41% starch-eating. In the group of White women, 7 and 10% reporting clay- and starch-eating, respectively. The amount of starch eaten ranged from 2−3 small lumps to 3 boxes (24 ounces) per day. The amount of clay eaten ranged from one tablespoon to one cup per day.

5.3.4.3. *Cooper (1957)—Pica: A Survey of the Historical Literature as Well as Reports From the Fields of Veterinary Medicine and Anthropology, the Present Study of Pica in Young Children, and a Discussion of Its Pediatric and Psychological Implications*

Cooper (1957) conducted a non-randomized survey response study in the 1950s of children age 7 months or older referred to a Baltimore, Maryland mental hygiene clinic. For 86 out of 784 children studied, parents or caretakers gave positive responses to the question, "Does your child have a habit, or did he ever have a habit, of eating dirt, plaster, ashes, etc.?" and identified dirt, or dirt combined with other substances, as the substance ingested. Cooper (1957) described a pattern of pica behavior, including ingesting substances other than soil, being most common between ages 2 and 4 or 5 years, with one of the 86 children ingesting clay at age 10 years and 9 months.

5.3.4.4. *Barltrop (1966)—The Prevalence of Pica*

Barltrop (1966) conducted a randomized survey response study of children born in Boston, Massachusetts between 1958 and 1962, inclusive, whose parents resided in Boston and who were neither illegitimate nor adopted. A stratified random subsample of 500 of these children was contacted for in-person caregiver interviews, in which a total of 186 families (37%) participated. A separate stratified subsample of 1,000 children was selected for a mailed survey, in which 277 (28%) of the families participated. Interview-obtained data regarding care-giver reports of pica (in this study is defined as placing non-food items in the mouth and swallowing them) behavior in all children ages 1 to 6 years in the 186 families (N = 439) indicated 19 had ingested dirt (defined as yard dirt, house dust, plant-pot soil, pebbles, ashes, cigarette ash, glass fragments, lint, and hair combings) in the preceding 14 days. It does not appear that these data were corrected for unequal selection probability in the stratified random sample, nor were they corrected for non-response bias. Interviews were conducted in the March/April time frame, presumably in 1964. Mail-survey obtained data regarding caregiver reports of pica in the preceding 14 days indicated that 39 of 277 children had ingested dirt, presumably using the same definition as above. Barltrop (1966) mentions several possible limitations of the study, including non-participation bias and respondents' memory, or recall, effects.

5.3.4.5. *Bruhn and Pangborn (1971)—Reported Incidence of Pica Among Migrant Families*

Bruhn and Pangborn (1971) conducted a survey among 91 low income families of migrant agricultural workers in California in May through August 1969. Families were of Mexican descent in two labor camps (Madison camp, 10 miles west of Woodland, and Davis camp, 10 miles east of Davis) and were "Anglo" families at the Harney Lane camp 17 miles north of Stockton. Participation was 34 of 50 families at the Madison camp, 31 of 50 families at the Davis camp, and 26 of 26 families at the Harney Lane camp. Respondents for the studied families (primarily wives) gave positive responses to open-ended questions such as "Do you know of anyone who eats dirt or laundry starch?" Bruhn and Pangborn (1971) apparently asked a modified version of this question pertaining to the respondents' own or relatives' families. They reported 18% (12 of 65) of Mexican families' respondents as giving positive responses for consumption of "dirt" among children within the Mexican respondents' own or relatives' families. They reported 42% (11 of 26) of "Anglo" families' respondents as giving positive responses for consumption of "dirt" among children within the Anglo respondents' own or relatives' families.

5.3.4.6. *Robischon (1971)—Pica Practice and Other Hand-Mouth Behavior and Children's Developmental Level*

A survey response sample of 19- to 24-month old children examined at an urban well-child clinic in the late 1960s or 1970 in an unspecified location indicated that 48 of the 130 children whose caregivers were interviewed, exhibited pica behavior (defined as "ate non-edibles more than once a week"). The specific substances eaten were reported for 30 of the 48 children. All except 2 of the 30 children habitually ate more than one non-edible substance. The soil and dust-like substances reported as eaten by these 30 children were: ashes (17), "earth" (5), dust (3), fuzz from rugs (2), clay (1), and pebbles/stones (1). Caregivers for some of the study subjects (between 0 and 52 of the 130 subjects, exact number not specified) reported that the children "ate non-edibles less than once a week."

5.3.4.7. *Bronstein and Dollar (1974)—Pica in Pregnancy*

The frequency and effects of pica behavior was investigated by Bronstein and Dollar (1974) in 410 pregnant, low-income women from both urban (N = 201) and rural (N = 209) areas in Georgia. The women selected were part of the Nutrition Demonstration Project, a study investigating the effect of nutrition on the outcome of the pregnancy, conducted at the Eugene Talmadge Memorial Hospital and University Hospital in Augusta, Georgia. During their initial prenatal visit, each patient was interviewed by a nutrition counselor who questioned her food frequency, social and dietary history, and the presence of pica. Patients were categorized by age, parity, and place of residence (rural or urban).

Of the 410 women interviewed, 65 (16%) stated that they practiced pica. A variety of substances were ingested, with laundry starch being the most common. There was no significant difference in the practice of pica between rural and urban women, although older rural women (20−35 years) showed a greater tendency to practice pica than younger rural or urban women (<20 years). The number of previous pregnancies did not influence the practice of pica. The authors noted that the frequency of pica among rural patients had declined from a previous study conducted 8 years earlier, and attributed the reduction to a program of intensified nutrition education and counseling provided in the area. No specific information on the amount of pica substances ingested was provided by this study, and the data are more than 30 years old.

5.3.4.8. *Hook (1978)—Dietary Cravings and Aversions During Pregnancy*

Hook (1978) conducted interviews of 250 women who had each delivered a live infant at two New York hospitals; the interviews took place in 1975. The mothers were first asked about any differences in consumption of seven beverages during their pregnancy, and the reasons for any changes. They were then asked, without mentioning specific items, about any cravings or aversions for other foods or non-food items that may have developed at any time during their pregnancy.

Non-food items reportedly ingested during pregnancy were ice, reported by three women, and chalk from a river clay bank, reported by one woman. In addition, one woman reported an aversion to non-food items (specific non-food item not reported). No quantity data were provided by this study.

5.3.4.9. *Binder et al. (1986)—Estimating Soil Ingestion: The Use of Tracer Elements in Estimating the Amount of Soil Ingested by Young Children*

Binder et al. (1986) used a tracer technique modified from a method previously used to measure soil ingestion among grazing animals to study the ingestion of soil among children 1 to 3 years of age who wore diapers. The children were studied during the summer of 1984 as part of a larger study of residents living near a lead smelter in East Helena, Montana. Soiled diapers were collected over a 3-day period from 65 children (42 males and 23 females), and composited samples of soil were obtained from the children's yards. Both excreta and soil samples were analyzed for aluminum, silicon, and titanium. These elements were found in soil but were thought to be poorly absorbed in the gut and to have been present in the diet only in limited quantities. Excreta measurements were obtained for 59 of the children.

Soil ingestion by each child was estimated on the basis of each of the three tracer elements using a standard assumed fecal dry weight of 15 g/day, and the following equation (5-2):

$$T_{i,e} = \frac{f_{i,e} \times F_i}{S_{i,e}} \qquad \text{(Eqn. 5-2)}$$

where:

$T_{i,e}$	=	estimated soil ingestion for child i based on element e (g/day),
$f_{i,e}$	=	concentration of element e in fecal sample of child i (mg/g),
F_i	=	fecal dry weight (g/day), and
$S_{i,e}$	=	concentration of element e in child i's yard soil (mg/g).

The analysis assumed that (1) the tracer elements were neither lost nor introduced during sample processing; (2) the soil ingested by children originates primarily from their own yards; and (3) that absorption of the tracer elements by children occurred in only small amounts. The study did not distinguish between ingestion of soil and house dust, nor did it account for the presence of the tracer elements in ingested foods or medicines.

The arithmetic mean quantity of soil ingested by the children in the Binder et al. (1986) study was estimated to be 181 mg/day (range 25 to 1,324) based on the aluminum tracer; 184 mg/day (range 31 to 799) based on the silicon tracer; and 1,834 mg/day (range 4 to 17,076) based on the titanium tracer (see Table 5-15). The overall mean soil ingestion estimate, based on the minimum of the three individual tracer estimates for each child, was 108 mg/day (range 4 to 708). The median values were 121 mg/day, 136 mg/day, and 618 mg/day for aluminum, silicon, and titanium, respectively. The 95th percentile values for aluminum, silicon, and titanium were 584 mg/day, 578 mg/day, and 9,590 mg/day, respectively. The 95th percentile value based on the minimum of the three individual tracer estimates for each child was 386 mg/day.

The authors were not able to explain the difference between the results for titanium and for the other two elements, but they speculated that unrecognized sources of titanium in the diet or in the laboratory processing of stool samples may have accounted for the increased levels. The frequency distribution graph of soil ingestion estimates based on titanium shows that a group of 21 children had particularly high titanium values (i.e., >1,000 mg/day). The remainder of the children showed titanium ingestion estimates at lower levels, with a distribution more comparable to that of the other elements.

5.3.4.10. *Clausing et al. (1987)—A Method for Estimating Soil Ingestion by Children*

Clausing et al. (1987) conducted a soil ingestion study with Dutch children using a tracer element methodology. Clausing et al. (1987) measured aluminum, titanium, and acid-insoluble residue contents of fecal samples from children aged 2 to 4 years attending a nursery school, and for samples of playground dirt at that school. Over a 5-day period, 27 daily fecal samples were obtained for 18 children. Using the average soil concentrations present at the school, and assuming a standard fecal dry weight of 10 g/day, soil ingestion was estimated for each tracer. Six hospitalized, bedridden children served as a control group, representing children who had very limited access to soil; eight daily fecal samples were collected from the hospitalized children.

Without correcting for the tracer element contribution from background sources, represented by the hospitalized children’s soil ingestion estimates, the aluminum-based soil ingestion estimates for the school children in this study ranged from 23 to 979 mg/day, the AIR-based estimates ranged from 48 to 362 mg/day, and the titanium-based estimates ranged from 64 to 11,620 mg/day. As in the Binder et al. (1986) study, a fraction of the children (6/18) showed titanium values above 1,000 mg/day, with most of the remaining children showing substantially lower values. Calculating an arithmetic mean quantity of soil ingested based on each fecal sample yielded 230 mg/day for aluminum; 129 mg/day for AIR, and 1,430 mg/day for titanium (see Table 5-16). Based on the LTM and averaging across each fecal sample, the arithmetic mean soil ingestion was estimated to be 105 mg/day with a population standard deviation of 67 mg/day (range 23 to 362 mg/day); geometric mean soil ingestion was estimated to be 90 mg/day. Use of the LTM assumed that "the maximum amount of soil ingested corresponded with the lowest estimate from the three tracers" (Clausing et al., 1987).

The hospitalized children’s arithmetic mean aluminum-based soil ingestion estimate was 56 mg/day; titanium-based estimates included estimates for three of the six children that exceeded 1,000 mg/day, with the remaining three children in the range of 28 to 58 mg/day (see Table 5-17). AIR measurements were not reported for the hospitalized children. Using the LTM method, the mean soil ingestion rate was estimated to be 49 mg/day with a population standard deviation of 22 mg/day (range 26 to 84 mg/day). The geometric mean soil ingestion rate was 45 mg/day. The hospitalized children's data suggested a major non-soil source of titanium for some children and a background non-soil source of aluminum. However, conditions specific to hospitalization (e.g., medications) were not considered.

Clausing et al. (1987) estimated that the average soil ingestion of the nursery school children was 56 mg/day, after subtracting the mean LTM soil ingestion for the hospitalized children (49 mg/day) from the nursery school children's mean LTM soil ingestion (105 mg/day), to account for background tracer intake from dietary and other non-soil sources.

5.3.4.11. *Calabrese et al. (1990)—Preliminary Adult Soil Ingestion Estimates: Results of a Pilot Study*

Calabrese et al. (1990) studied six adults to evaluate the extent to which they ingest soil. This adult study was originally part of the children soil ingestion study (Calabrese et al., 1989) and was used to validate part of the analytical methodology used in the children's study. The participants were six healthy adults, three males and three females, 25−41 years old. Each volunteer ingested one empty gelatin capsule at breakfast and one at dinner Monday, Tuesday, and Wednesday during the first week of the study. During the second week, they ingested 50 milligrams of sterilized soil within a gelatin capsule at breakfast and at dinner (a total of 100 milligrams of sterilized soil per day) for 3 days. For the third week, the participants ingested 250 milligrams of sterilized soil in a gelatin capsule at breakfast and at dinner (a total of 500 milligrams of soil per day) during the 3 days. Duplicate meal samples (food and beverage) were collected from the six adults. The sample included all foods ingested from breakfast Monday, through the evening meal Wednesday during each of the 3 weeks. In addition, all medications and vitamins ingested by the adults were collected. Total excretory output was collected from Monday noon through Friday midnight over 3 consecutive weeks.

Data obtained from the first week, when empty gelatin capsules were ingested, were used to estimate soil intake by adults. On the basis of recovery values, Al, Si, Y, and Zr were considered the most valid tracers. The mean values for these four tracers were: Al, 110 milligrams; Si, 30 milligrams; Y, 63 milligrams; and Zr, 134 mg. A limitation of this study is the small sample size.

5.3.4.12. *Cooksey (1995)—Pica and Olfactory Craving of Pregnancy: How Deep Are the Secrets?*

Postpartum interviews were conducted between 1992 and 1994 of 300 women at a mid-western hospital, to document their experiences of pica behavior. The majority of women were Black and low-income, and ranged in age from 13 to 42 years. In addition to questions regarding nutrition, each woman was asked if during her pregnancy she experienced a craving to eat ice or other things that are not food.

Of the 300 women, 194 (65%) described ingesting one or more pica substances during their pregnancy, and the majority (78%) ate ice/freezer frost alone or in addition to other pica substances. Reported quantities of items ingested on a daily basis were three to four 8-pound bags of ice, two to three boxes of cornstarch, two cans of baking powder, one cereal bowl of dirt, five quarts of freezer frost, and one large can of powdered cleanser.

5.3.4.13. *Smulian et al. (1995)—Pica in a Rural Obstetric Population*

In 1992, Smulian et al. (1995) conducted a survey response study of pica in a convenience sample of 125 pregnant women in Muscogee County, Georgia, who ranged in age from 12 to 37 years. Of these, 73 were Black, 47 were White, 4 were Hispanic, and 1 was Asian. Interviews were conducted at the time of the first prenatal visit, using non-directive questionnaires to obtain information regarding substances ingested as well as patterns of pica behavior and influences on pica behavior. Only women ingesting non-food items were considered to have pica. Ingestion of ice was included as a pica behavior only if the ice was reported to be ingested multiple times per day, if the ice was purchased solely for ingestion, or if the ice was obtained from an unusual source such as freezer frost.

The overall prevalence of pica behavior in this study was 14.4% (18 of 125 women), and was highest among Black women (17.8%). There was no significant difference between groups with respect to age, race, weight, or gestational age at the time of enrollment in the study. The most common form of pica was ice eating (pagophagia), reported by 44.4% of the patients. Nine of the women reported information on the frequency and amount of the substances they were ingesting. Of these women, 66.7% reported daily consumption and 33.3% reported pica behavior three times per week. Soap, paint chips, or burnt matches were reportedly ingested 3 days per week. One patient ate ice 60 times per week. Women who ate dirt or clay reported ingesting 0.5−1 pound per week. The largest amount of ice consumed was five pounds per day.

5.3.4.14. *Grigsby et al. (1999)—Chalk Eating in Middle Georgia: A Culture-Bound Syndrome of Pica?*

Grigsby et al. (1999) investigated the ingestion of kaolin, also known as white dirt, chalk, or white clay, in the central Georgia Piedmont area as a culture-bound syndrome. A total of 21 individuals who consumed kaolin at the time or had a history of consuming kaolin were interviewed, using a seven-item, one-page interview protocol. All of those interviewed were Black, ranging in age from 28 to 88 years (mean age of 46.5 years), and all were female except for one.

Reasons for eating kaolin included liking the taste, being pregnant, craving it, and to gain weight. Eight respondents indicated that they obtained the kaolin from others, five reported getting it directly from the earth, four purchased it from a store, and two obtained it from a kaolin pit mine. The majority of the respondents reported that they liked the taste and feel of the kaolin as they ate it. Only three individuals reported knowing either males or White persons who consumed kaolin. Most individuals were not forthcoming in discussing their ingestion of kaolin and recognized that their behavior was unusual.

The study suggests that kaolin-eating is primarily practiced by Black women who were introduced to the behavior by family members or friends, during childhood or pregnancy. The authors concluded that kaolin ingestion is a culturally-transmitted form of pica, not associated with any other psychopathology. Although information on kaolin eating habits and attitudes were provided by this study, no quantitative information on consumption was included, and the sample population was small and non-random.

5.3.4.15. *Ward and Kutner (1999)—Reported Pica Behavior in a Sample of Incident Dialysis Patients*

Structured interviews were conducted with a sample of 226 dialysis patients in the metropolitan Atlanta, Georgia area from September 1996 to September 1997. Interviewers were trained in nutrition data collection methods, and patients also received a 3-day diet diary that they were asked to complete and return by mail. If a subject reported a strong past or current food or non-food craving, a separate form was used to collect information to determine if this was a pica behavior.

Pica behavior was reported by 37 of the dialysis patients studied (16%), and most of these patients (31 of 37) reported that they were currently practicing some form of pica behavior. The patients' race and sex were significantly associated with pica behavior, with Black patients and women making up 86% and 84% of those reporting pica, respectively. Those reporting pica behavior were also younger than the remainder of the sample, and approximately 2 described a persistent craving for ice. Other pica items reportedly consumed included starch, dirt, flour, or aspirin.

5.3.4.16. *Simpson et al. (2000)—Pica During Pregnancy in Low-Income Women Born in Mexico*

Simpson et al. (2000) interviewed 225 Mexican-born women, aged 18−42 years (mean age of 25 years), using a questionnaire administered in Spanish. Subjects were recruited by approaching women in medical facilities that served low-income populations in the cities of Ensenada, Mexico ($N = 75$), and Santa Ana, Bakersfield, and East Los Angeles, California ($N = 150$). Criteria for participation were that the women had to be Mexican-born, speak Spanish as their primary language, and be pregnant or have been pregnant within the past year. Only data for U.S. women are included in this handbook.

Pica behavior was reported in 31% of the women interviewed in the United States. Table 5-18 shows the items ingested and the number of women reporting the pica behavior. Of the items ingested, only ice was said to be routinely eaten outside of pregnancy, and was only reported by U.S. women, probably because none of the low-income women interviewed in Mexico owned a refrigerator. Removing the 12 women who reported eating only ice from the survey lowers the percentage of U.S. women who reported pica behavior to 23%. Women said they engaged in pica behavior because of the taste, smell, or texture of the items, for medicinal purposes, or because of advice from someone, and one woman reported eating clay for religious reasons. Magnesium carbonate, a pica item not found to be previously reported in the literature, was reportedly consumed by 17% of women. The amount of magnesium carbonate ingested ranged from a quarter of a block to five blocks per day; the blocks were approximately the size of a 35-mm film box. No specific quantity information on the amounts of pica substances ingested was provided in the study.

5.3.4.17. *Obialo et al. (2001)—Clay Pica Has No Hematologic or Metabolic Correlate to Chronic Hemodialysis Patients*

A total of 138 dialysis patients at the Morehouse School of Medicine, Atlanta, Georgia, were interviewed about their unusual cravings or food habits. The patients were Black and ranged in age from 37 to 78 years.

Thirty of the patients (22%) reported some form of pica behavior, while 13 patients (9.4%) reported clay pica. The patients with clay pica reported daily consumption of 225−450 grams of clay.

5.3.4.18. *Klitzman et al. (2002)—Lead Poisoning Among Pregnant Women in New York City: Risk Factors and Screening Practices*

Klitzman et al. (2002) interviewed 33 pregnant women whose blood lead levels were >20 µg/dL as reported to the New York City Department of Health between 1996 and 1999. The median age of the women was 24 years (range of 15 to 43 years), and the majority were foreign born. The women were interviewed regarding their work, reproductive and lead exposure history. A home visit was also conducted and included a visual inspection and a colorimetric swab test; consumable items suspected to contain lead were sent to a laboratory for analysis.

There were 13 women (39%) who reported pica behavior during their current pregnancies. Of these, 10 reported eating soil, dirt or clay, 2 reported pulverizing and eating pottery, and 1 reported eating soap. One of the women reported eating approximately one quart of dirt daily from her backyard for the past three months. No other quantity data were reported.

5.3.5. Relevant Studies of Secondary Analysis

The secondary analysis literature on soil and dust ingestion rates gives important insights into methodological strengths and limitations. The tracer element studies described in this section are grouped to some extent according to methodological issues associated with the tracer element methodology. These methodological issues include attempting to determine the origins of apparent positive and negative bias in the methodologies, including: food input/fecal output misalignment; missed fecal samples; assumptions about children's fecal weights; particle sizes of, and relative contributions of soils and dusts to total soil and dust ingestion; and attempts to identify a "best" tracer element or combination of tracer elements. Potential error from using short-term studies' estimates for long term soil and dust ingestion behavior estimates is also discussed.

5.3.5.1. *Stanek and Calabrese (1995a)—Daily Estimates of Soil Ingestion in Children*

Stanek and Calabrese (1995a) presented a methodology that links the physical passage of food and fecal samples to construct daily soil ingestion estimates from daily food and fecal trace-element concentrations. Soil ingestion data for children obtained from the Amherst study (Calabrese et al., 1989) were reanalyzed by Stanek and Calabrese (1995a). A lag period of 28 hours between food intake and fecal output was assumed for all respondents. Day 1 for the food sample corresponded to the 24-hour period from midnight on Sunday to midnight on Monday of a study week; day 1 of the fecal sample corresponded to the 24-hour period from noon on Monday to noon on Tuesday. Based on these definitions, the food soil equivalent was subtracted from the fecal soil equivalent to obtain an estimate of soil ingestion for a trace element. A daily overall ingestion estimate was constructed for each child as the median of trace element values remaining after tracers falling outside of a defined range around the overall median were excluded.

Table 5-19 presents adjusted estimates, modified according to the input/output misalignment correction, of mean daily soil ingestion per child (mg/day) for the 64 study participants. The approach adopted in this paper led to changes in ingestion estimates from those presented in Calabrese et al. (1989).

Estimates of children's soil ingestion projected over a period of 365 days were derived by fitting lognormal distributions to the overall daily soil ingestion estimates using estimates modified according to the input/output misalignment correction (see Table 5-20). The estimated median value of the 64 respondents' daily soil ingestion averaged over a year was 75 mg/day, while the 95th percentile was 1,751 mg/day. In developing the 365-day soil ingestion estimates, data that were obtained over a short period of time (as is the case with all available soil ingestion studies) were extrapolated over a year. The 2-week study period may not reflect variability in tracer element ingestion over a year. While Stanek and Calabrese (1995a) attempted to address this through modeling of the long term ingestion, new uncertainties were introduced through the parametric modeling of the limited subject day data.

5.3.5.2. *Calabrese and Stanek (1992a)—What Proportion of Household Dust is Derived From Outdoor Soil?*

Calabrese and Stanek (1992a) estimated the amount of outdoor soil in indoor dust using statistical modeling. The model used soil and dust data from the 60 households that participated in the Calabrese et al. (1989) study, by preparing scatter plots of each tracer's concentration in soil versus dust. Correlation analysis of the scatter plots was performed. The scatter plots showed little evidence of a consistent relationship between outdoor soil and indoor dust concentrations. The model estimated the proportion of outdoor soil in indoor dust using the simplifying assumption that the following variables were constants in all houses: the amount of dust produced every day from both indoor and outdoor sources; the proportion of indoor dust due to outdoor soil; and the concentration of the tracer element in dust produced from indoor sources. Using these assumptions, the model predicted that 31.3% by weight of indoor dust came from outdoor soil. This model was then used to adjust the soil ingestion estimates from Calabrese et al. (1989).

5.3.5.3. *Calabrese et al. (1996)—Methodology to Estimate the Amount and Particle Size of Soil Ingested by Children: Implications for Exposure Assessment at Waste Sites*

Calabrese et al. (1996) examined the hypothesis that one cause of the variation between tracers seen in soil ingestion studies could be related to differences in soil tracer concentrations by particle size. This study, published prior to the Calabrese et al. (1997b) primary analysis study results, used laboratory analytical results for the Anaconda, Montana soil's tracer concentration after it had been sieved to a particle size of <250 µm in diameter [it was sieved to <2 mm soil particle size in Calabrese et al. (1997b)]. The smaller particle size was examined based on the assumption that children principally ingest soil of small particle size adhering to fingertips and under fingernails. For five of the tracers used in the original study (aluminum, silicon, titanium, yttrium, and zirconium), soil concentration was not changed by particle size. However, the soil concentrations of three tracers (lanthanum, cerium, and neodymium) were increased 2- to 4-fold at the smaller soil particle size. Soil ingestion estimates for these three tracers were decreased by approximately 60% at the 95th percentile compared to the Calabrese et al. (1997b) results.

5.3.5.4. *Stanek et al. (1999)—Soil Ingestion Estimates for Children in Anaconda Using Trace Element Concentrations in Different Particle Size Fractions*

Stanek et al. (1999) extended the findings from Calabrese et al. (1996) by quantifying trace element concentrations in soil based on sieving to particle sizes of 100−250 µm and to particle sizes of 53 to <100 µm. The earlier study (Calabrese et al., 1996) used particle sizes of 0−2 µm and 1−250 µm. This study used the data from soil concentrations from the Anaconda, Montana site reported by Calabrese et al. (1997b). Results of the study indicated that soil concentrations of aluminum, silicon, and titanium did not increase at the two finer particle size ranges measured. However, soil concentrations of cerium, lanthanum, and neodymium increased by a factor of 2.5 to 4.0 in the 100−250 µm particle size range when compared with the 0−2 µm particle size range. There was not a significant increase in concentration in the 53−100 µm particle size range.

5.3.5.5. *Stanek and Calabrese (2000)—Daily Soil Ingestion Estimates for Children at a Superfund Site*

Stanek and Calabrese (2000) reanalyzed the soil ingestion data from the Anaconda study. The authors assumed a lognormal distribution for the soil ingestion estimates in the Anaconda study to predict average soil ingestion for children over a longer time period. Using "best linear unbiased predictors," the authors predicted 95th percentile soil ingestion values over time periods of 7 days, 30 days, 90 days, and 365 days. The 95th percentile soil ingestion values were predicted to be 133 mg/day over 7 days, 112 mg/day over 30 days, 108 mg/day over 90 days, and 106 mg/day over 365 days. Based on this analysis, estimates of the distribution of longer term average soil ingestion are expected to be narrower, with the 95th percentile estimates being as much as 25% lower (Stanek and Calabrese, 2000).

5.3.5.6. *Stanek et al. (2001a)—Biasing Factors for Simple Soil Ingestion Estimates in Mass Balance Studies of Soil Ingestion*

In order to identify and evaluate biasing factors for soil ingestion estimates, the authors developed a simulation model based on data from previous soil ingestion studies. The soil ingestion data used in this model were taken from Calabrese et al. (1989) (the Amherst study); Davis et al. (1990) (southeastern Washington State); Calabrese et al. (1997b) (the Anaconda study); and Calabrese et al. (1997a) (soil-pica in Massachusetts), and relied only on the aluminum and silicon trace element estimates provided in these studies.

Of the biasing factors explored, the impact of study duration was the most striking, with a positive bias of more than 100% for 95th percentile estimates in a 4-day tracer element study. A smaller bias was observed for the impact of absorption of trace elements from food. Although the trace elements selected for use in these studies are believed to have low absorption, whatever amount is not accounted for will result in an underestimation of the soil ingestion distribution. In these simulations, the absorption of trace elements from food of up to 30% was shown to negatively bias the estimated soil ingestion distribution by less than 20 mg/day. No biasing effect was found for misidentifying play areas for soil sampling (i.e., ingested soil from a yard other than the subject's yard).

5.3.5.7. *Stanek et al. (2001b)—Soil Ingestion Distributions for Monte Carlo Risk Assessment in Children*

Stanek et al. (2001b) developed "best linear unbiased predictors" to reduce the biasing effect of short-term soil ingestion estimates. This study estimated the long-term average soil ingestion distribution using daily soil ingestion estimates from children who participated in the Anaconda, Montana study. In this long-term (annual) distribution, the soil ingestion estimates were: mean 31, median 24, 75th percentile 42, 90th percentile 75, and 95th percentile 91 mg/day.

5.3.5.8. *Von Lindern et al. (2003)—Assessing Remedial Effectiveness Through the Blood Lead: Soil/Dust Lead Relationship at the Bunker Hill Superfund Site in the Silver Valley of Idaho*

Similar to Hogan et al. (1998), von Lindern et al. (2003) used the IEUBK model to predict blood lead levels in a non-random sample of several hundred children ages 0−9 years in an area of northern Idaho from 1989−1998 during community-wide soil remediation. Von Lindern et al. (2003) used the IEUBK default soil and dust ingestion rates together with observed house dust/soil lead levels (and imputed values based on community soil and dust lead levels, when observations were missing). The authors compared the predicted blood lead levels with observed blood lead levels and found that the default IEUBK soil and dust ingestion rates and lead bioavailability value over-predicted blood lead levels, with the over-prediction decreasing as the community soil remediation progressed. The authors stated that the over-prediction may have been caused either by a default soil and dust ingestion that was too high, a default bioavailability value for lead that was too high, or some combination of the two. They also noted under-predictions for some children, for whom follow up interviews revealed exposures to lead sources not accounted for by the model, and noted that the study sample included many children with a short residence time within the community.

Von Lindern et al. (2003) developed a statistical model that apportioned the contributions of community soils, yard soils of the residence, and house dust to lead intake; the models' results suggested that community soils contributed more (50%) than neighborhood soils (28%) or yard soils (22%) to soil found in house dust of the studied children.

5.3.5.9. *Gavrelis et al. (2011)—An Analysis of the Proportion of the U.S. Population That Ingests Soil or Other Non-Food Substances*

Gavrelis et al. (2011) evaluated the prevalence of the U.S. population that ingests non-food substances such as soil, clay, starch, paint, or plaster. Data were compiled from the National Health and Nutrition Examination Survey (NHANES) collected from 1971−1975 (NHANES I) and 1976−1980 (NHANES II), which represent a complex, stratified, multistage, probability-cluster design and include nationwide probability samples of approximately 21,000 and 25,000 study participants, respectively. NHANES I surveyed people aged 1 to 74 years and NHANES II surveyed those 6 months to 74 years. The study population included women of childbearing age, people with low income status, the elderly, and preschool children, who represented an oversampling of specific groups in the population that were believed to have high risks for malnutrition. The survey questions were demographic, socioeconomic, dietary, and health-related queries, and included specific questions regarding soil and non-food substance ingestion. Survey questions for children under 12 years asked whether they consumed non-food substances including dirt or clay, starch, paint or plaster, and other materials (NHANES I) or about consumption of clay, starch, paint or plaster, dirt, and other materials (NHANES II). For participants over 12 years of age, the survey questions asked only about consumption of dirt or clay, starch, and other materials (NHANES I) or about non-food substances including clay, starch, and other materials (NHANES II). Age groupings used in this analysis vary slightly from the age group categories established by U.S. EPA and described in *Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants* (U.S. EPA, 2005). Other demographic parameters included sex (including pregnant and non-pregnant females); race (White, Black, and other); geography (urban and rural, with "urban" defined as populations ≥2,500); income level (ranging from $0−$9,999 up to >$20,000, or not stated); and highest grade head of household (population under 18 years) or respondent (population >18 years) attended. For statistical analysis, frequency estimates were generated for the proportion of the total U.S. population that reported consumption of dirt, clay, starch, paint or plaster, or other materials "considered unusual" using the appropriate NCHS sampling weights and responses to the relevant questions in NHANES I and II. NHANES I and II were evaluated separately, because the data sets did not provide components of the weight variable separately (i.e., probability of selection, non-response adjustment weight, and post-stratification weight).

Although the overall prevalence estimates were higher in NHANES I compared with NHANES II, similar patterns were generally observed across substance types and demographic groups studied. For NHANES I, the estimated prevalence of all non-food substance consumption in the United States for all ages combined was 2.5% (95% Confidence Interval [CI]: 2.2−2.9%), whereas for NHANES II, the estimated prevalence of all non-food substance consumption in the United States for all ages combined was 1.1% (95% CI: 1.0−1.2%). Table 5-21 provides the prevalence estimates by type of substance consumed for all ages combined. By type of substance, the estimated prevalence was greatest for dirt and clay consumption and lowest for starch. Figure 5-1, Figure 5-2, and Figure 5-3, respectively, show the prevalence of non-food substance consumption by age, race, and income. The most notable differences were seen across age, race (Black versus White), and income groups. For both NHANES I and II, prevalence for the ingestion of all non-food substances decreased with increasing age, was higher among Blacks (5.7%; 95% CI: 4.4−7.0%) as compared to Whites (2.1%; 95% CI: 1.8−2.5%), and was inversely related to income level, with prevalence of non-food consumption decreasing as household income increased. The estimated prevalence of all non-food substances for the 1 to <3 year age category was at least twice that of the next oldest category (3 to <6 years). Prevalence estimates were 22.7% (95% CI: 20.1–25.3%) for the 1 to <3 year age group based on NHANES I and 12% based on NHANES II. In contrast, prevalence estimates for the >21 year age group was 0.7% (95% CI: 0.5–1.0%) and 0.4% (95% CI: 0.3–0.5%) for NHANES I and NHANES II, respectively. Other differences related to geography (i.e., urban and rural), highest grade level of the household head, and sex were less remarkable. For NHANES I, for example, the estimated prevalence of non-food substance consumption was only slightly higher among females (2.9%; CI: 2.3−3.5%) compared to males (2.1%; CI: 1.8−2.5%) of all ages. For pregnant females, prevalence estimates (2.5%; 95% CI: 0.0−5.6%) for those 12 years and over were more than twice those for non-pregnant females (1.0%; 95% CI: 0.7−1.4%).

5.4. LIMITATIONS OF STUDY METHODOLOGIES

The three types of information needed to provide recommendations to exposure assessors on soil and dust ingestion rates among U.S. children include quantities of soil and dust ingested, frequency of high soil and dust ingestion episodes, and prevalence of high soil and dust ingesters. The methodologies provide different types of information: the tracer element, biokinetic model comparison, and activity pattern methodologies provide information on quantities of soil and dust ingested; the tracer element methodology provides limited evidence of the frequency of high soil ingestion episodes; the survey response methodology can shed light on prevalence of high soil ingesters and frequency of high soil ingestion episodes. The methodologies used to estimate soil and dust ingestion rates and prevalence of soil and dust ingestion behaviors have certain limitations, when used for the purpose of developing recommended soil and dust ingestion rates. These limitations may not have excluded specific studies from use in the development of recommended ingestion rates, but have been noted throughout this handbook. This section describes some of the known limitations, presents an evaluation of the current state of the science for U.S. children's soil and dust ingestion rates, and describes how the limitations affect the confidence ratings given to the recommendations.

5.4.1. Tracer Element Methodology

This section describes some previously identified limitations of the tracer element methodology as it has been implemented by U.S. researchers, as well as additional potential limitations that have not been explored. Some of these same limitations would also apply to the Dutch and Jamaican studies that used a control group of hospitalized children to account for dietary and pharmaceutical tracer intakes.

Binder et al. (1986) described some of the major and obvious limitations of the early U.S. tracer element methodology as follows:

> [T]he algorithm assumes that children ingest predominantly soil from their own yards and that concentrations of elements in composite soil samples from front and back yards are representative of overall concentrations in the yards....children probably eat a combination of soil and dust; the algorithm used does not distinguish between soil and dust ingestion....fecal sample weights...were much lower than expected...the assumption that aluminum, silicon and titanium are not absorbed is not entirely true....dietary intake of aluminum, silicon and titanium is not negligible when compared with the potential intake of these elements from soil....Before accepting these estimates as true values of soil ingestion in toddlers, we need a better understanding of the metabolisms of aluminum, silicon and titanium in children, and the validity of the assumptions we made in our calculations should be explored further.

The subsequent U.S. tracer element studies (Davis and Mirick, 2006; Calabrese et al., 1997b; Barnes, 1990; Davis et al., 1990; Calabrese et al., 1989) made some progress in addressing some of the Binder et al. (1986) study's stated limitations.

Regarding the issue of non-yard (community-wide) soil as a source of ingested soil, one study (Barnes, 1990; Calabrese et al., 1989) addressed this issue to some extent, by including samples of children's daycare center soil in the analysis. Calabrese et al. (1997b) attempted to address the issue by excluding children in daycare from the study sample frame. Homogeneity of community soils' tracer element content would play a role in whether this issue is an important biasing factor for the tracer element studies' estimates. Davis et al. (1990) evaluated community soils' aluminum, silicon, and titanium content and found little variation among 101 yards throughout the three-city area. Stanek et al. (2001a) concluded that there was "minimal impact" on estimates of soil ingestion due to mis-specifying a child's play area.

Regarding the issue of soil and dust both contributing to measured tracer element quantities in excreta samples, the key U.S. tracer element studies all attempted to address the issue by including samples of household dust in the analysis, and in some cases estimates are presented in the published articles that adjust soil ingestion estimates on the basis of the measured tracer elements found in the household dust. The relationship between soil ingestion rates and indoor settled dust ingestion rates has been evaluated in some of the secondary studies (Calabrese and Stanek, 1992a). An issue similar to the community-wide soil exposures in the previous paragraph could also exist with community-wide indoor dust exposures (such as dust found in schools and community buildings occupied by study subjects during or prior to the study period). A portion of the community-wide indoor dust exposures (due to occupying daycare facilities) was addressed in the Calabrese et al. (1989) and Barnes (1990) studies, but not in the other three key tracer element studies. In addition, if the key studies' vacuum cleaner collection method for household and daycare indoor settled dust samples influenced tracer element composition of indoor settled dust samples, the dust sample collection method would be another area of uncertainty with the key studies' indoor dust related estimates. The survey response studies suggest that some young children may prefer ingesting dust to ingesting soil. The existing literature on soil versus dust sources of children's lead exposure may provide useful information that has not yet been compiled for use in soil and dust ingestion recommendations.

Regarding the issue of fecal sample weights and the related issue of missing fecal and urine samples, the key tracer element studies have varying strengths and limitations. The Calabrese et al. (1989) article stated that wipes and toilet paper were not collected by the researchers, and thus underestimates of fecal quantities may have occurred. Calabrese et al. (1989) stated that cotton cloth diapers were supplied for use during the study; commodes apparently were used to collect both feces and urine for those children who were not using diapers. Barnes (1990) described cellulose and polyester disposable diapers with significant variability in silicon and titanium content and suggested that children's urine was not included in the analysis. Thus, it is unclear to what extent complete fecal and urine output was obtained, for each study subject. The Calabrese et al. (1997b) study did not describe missing fecal samples and did not state whether urinary tracer element quantities were used in the soil and dust ingestion estimates, but stated that wipes and toilet paper were not collected. Missing fecal samples may have resulted in negative bias in the estimates from both of these studies. Davis et al. (1990) and Davis and Mirick (2006) were limited to children who no longer wore diapers.

Missed fecal sample adjustments might affect those studies' estimates in either a positive or negative direction, due to the assumptions the authors made regarding the quantities of feces and urine in missed samples. Adjustments for missing fecal and urine samples could introduce errors sufficient to cause negative estimates if missed samples were heavier than the collected samples used in the soil and dust ingestion estimate calculations.

Regarding the issue of dietary intake, the key U.S. tracer element studies have all addressed dietary (and non-dietary, non-soil) intake by subtracting calculated estimates of these sources of tracer elements from excreta tracer element quantities, or by providing study subjects with personal hygiene products that were low in tracer element content. Applying the food and non-dietary, non-soil corrections required subtracting the tracer element contributions from these non-soil sources from the measured fecal/urine tracer element quantities. To perform this correction required assumptions to be made regarding the gastrointestinal transit time, or the time lag between inputs (food, non-dietary non-soil, and soil) and outputs (fecal and urine). The gastrointestinal transit time assumption introduced a new potential source of bias that some authors (Stanek and Calabrese, 1995a) called input/output misalignment or transit time error. Stanek and Calabrese (1995b) attempted to correct for this transit time error by using the BTM and focusing estimates on those tracers that had a low food/soil tracer concentration ratios. The lag time may also be a function of age. Davis et al. (1990) and Davis and Mirick (2006) assumed a 24-hour lag time in contrast to the 28-hour lag times used in Calabrese et al. (1989); Barnes (1990); and Calabrese et al. (1997b). ICRP (2003) suggested a lag time of 37 hours for one year old children and 5 to 15 year old children. Stanek and Calabrese (1995a) describe a method designed to reduce bias from this error source.

Regarding gastrointestinal absorption, the authors of three of the studies appeared to agree that the presence of silicon in urine represented evidence that silicon was being absorbed from the gastrointestinal tract (Davis and Mirick, 2006; Barnes, 1990; Davis et al., 1990; Calabrese et al., 1989). There was some evidence of aluminum absorption in Calabrese et al. (1989); Barnes (1990); Davis and Mirick (2006) stated that aluminum and titanium did not appear to have been absorbed, based on low urinary levels. Davis et al. (1990) stated that silicon appears to have been absorbed to a greater degree than aluminum and titanium, based on urine concentrations.

Aside from the gastrointestinal absorption, lag time, and missed fecal sample issues, Davis and Mirick (2006) offered another possible explanation for the negative soil and dust ingestion rates estimated for some study participants. Negative values result when the tracer amount in food and medicine is greater than that in urine/fecal matter. Given that some analytical error may occur, any overestimation of tracer amounts in the food samples would be greater than an overestimation in urine/feces, since the food samples were many times heavier than the urine and fecal samples.

Another limitation on accuracy of tracer element-based estimates of soil and dust ingestion relates to inaccuracies inherent in environmental sampling and laboratory analytical techniques. The "percent recovery" of different tracer elements varies [according to validation of the study methodology performed with adults who swallowed gelatin capsules with known quantities of sterilized soil, as part of the Calabrese et al. (1997b; 1989) studies]. Estimates based on a particular tracer element with a lower or higher recovery than the expected 100% in any of the study samples would be influenced in either a positive or negative direction, depending on the recoveries in the various samples and their degree of deviation from 100% (Calabrese et al., 1989). Soil/dust size fractions, and digestion/extraction methods of sample analysis may be additional limitations.

Davis et al. (1990) offered an assessment of the impact of swallowed toothpaste on the tracer-based estimates by adjusting estimates for those children whose caregivers reported that they had swallowed toothpaste. Davis et al. (1990) had supplied study children with toothpaste that had been pre-analyzed for its tracer element content, but it is not known to what extent the children actually used the supplied toothpaste. Similarly, Calabrese et al. (1997b; 1989) supplied children in the Amherst, Massachusetts and Anaconda, Montana studies with toothpaste containing low levels of most tracers, but it is unclear to what extent those children used the supplied toothpaste.

Other research suggests additional possible limitations that have not yet been explored. First, lymph tissue structures in the gastrointestinal tract might serve as reservoirs for titanium dioxide food additives and soil particles, which could bias estimates either upward or downward depending on tracers' entrapment within, or release from, these reservoirs during the study period (ICRP, 2003; Powell et al., 1996; Shepherd et al., 1987). Second, gastrointestinal uptake of silicon may have occurred, which could bias those estimates downward. Evidence of silicon's role in bone formation (Carlisle, 1980) supported by newer research on dietary silicon uptake (Jugdaohsingh et al., 2002); Van Dyck et al. (2000) suggests a possible negative bias in the silicon-based soil ingestion estimates, depending on the quantities of silicon absorbed by growing children. Third, regarding the potential for swallowed toothpaste to bias soil ingestion estimates upward, commercially available toothpaste may contain quantities of titanium and perhaps silicon and aluminum in the range that could be expected to affect the soil and dust ingestion estimates. Fourth, for those children who drank bottled or tap water during the study period, and did not include those drinking water samples in their duplicate food samples, slight upward bias may exist in some of the estimates for those children, since drinking water may contain small, but relevant, quantities of silicon and potentially other tracer elements. Fifth, the tracer element studies conducted to date have not explored the impact of soil properties' influence on toxicant uptake or excretion within the gastrointestinal tract. Nutrition researchers investigating influence of clay geophagy behavior on human nutrition have begun using in vitro models of the human digestion (Dominy et al., 2004; Hooda et al., 2004). A recent review (Wilson, 2003) covers a wide range of geophagy research in humans and various hypotheses proposed to explain soil ingestion behaviors, with emphasis on the soil properties of geophagy materials.

5.4.2. Biokinetic Model Comparison Methodology

It is possible that the IEUBK biokinetic model comparison methodology contained sources of both positive and negative bias, like the tracer element studies, and that the net impact of the competing biases was in either the positive or negative direction. U.S. EPA's judgment about the major sources of bias in biokinetic model comparison studies is that there may be several significant sources of bias. The first source of potential bias was the possibility that the biokinetic model failed to account for sources of lead exposure that are important for certain children. For these children, the model might either under-predict, or accurately predict, blood lead levels compared to actual measured lead levels. However, this result may actually mean that the default assumed lead intake rates via either soil and dust ingestion, or another lead source that is accounted for by the model, are too high. A second source of potential bias was use of the biokinetic model for predicting blood lead levels in children who have not spent a significant amount of time in the areas characterized as the main sources of environmental lead exposure. Modeling this population could result in either upward or downward biases in predicted blood lead levels. Comparing upward-biased predictions with actual measured blood lead levels and finding a relatively good match could lead to inferences that the model's default soil and dust ingestion rates are accurate, when in fact the children's soil and dust ingestion rates, or some other lead source, were actually higher than the default assumption. A third source of potential bias was the assumption within the model itself regarding the biokinetics of absorbed lead, which could result in either positively or negatively biased predictions and the same kinds of incorrect inferences as the second source of potential bias.

In addition, there was no extensive sensitivity analysis. The calibration step used to fix model parameters limits the degree that most parameters can reasonably be varied. Second, the IEUBK model was not designed to predict blood lead levels greater than 25−30 µg/dL; there are few data to develop such predictions and less to validate them. If there are site-specific data that indicate soil ingestion rates (or other ingestion/intake rates) are higher than the defaults on average (not for specific children), the site-specific data should be considered. U.S. EPA considers the default IEUBK value of 30% reasonable for most data sets/sites. Bioavailability has been assayed for soils similar to those in the calibration step and the empirical comparison data sets; 30% was used in the calibration step, and is therefore recommended for similar sites. The default provides a reasonable substitute when there are no specific data. Speciation of lead compounds for a particular exposure scenario could support adjusting bioavailability if they are known to differ strongly from 30%. In general, U.S. EPA supports using bioavailability rates determined for the particular soils of interest if available.

5.4.3. Activity Pattern Methodology

The limitations associated with the activity pattern methodology relate to the availability and quality of the underlying data used to model soil ingestion rates. Real-time hand recording, where observations are made by trained professionals (rather than parents), may offer the advantage of consistency in interpreting visible behaviors and may be less subjective than observations made by someone who maintains a care giving relationship to the child. On the other hand, young children's behavior may be influenced by the presence of unfamiliar people (Davis et al., 1995). Groot et al. (1998) indicated that parent observers perceived that deviating from their usual care giving behavior by observing and recording mouthing behavior appeared to have influenced the children's behavior. With video-transcription methodology, an assumption is made that the presence of the videographer or camera does not influence the child's behavior. This assumption may result in minimal biases introduced when filming newborns, or when the camera and videographer are not visible to the child. However, if the children being studied are older than newborns and can see the camera or videographer, biases may be introduced. Ferguson et al. (2006) described apprehension caused by videotaping and described situations where a child's awareness of the videotaping crew caused "play-acting" to occur, or parents indicated that the child was behaving differently during the taping session. Another possible source of measurement error may be introduced when children's movements or positions cause their mouthing not to be captured by the camera. Data transcription errors can bias results in either the negative or positive direction. Finally, measurement error can occur if situations arise in which care givers are absent during videotaping and researchers must stop videotaping and intervene to prevent risky behaviors (Zartarian et al., 1995). Survey response studies rely on responses to questions about a child's mouthing behavior posed to parents or care givers. Measurement errors from these studies could occur for a number of different reasons, including language/dialect differences between interviewers and respondents, question wording problems and lack of definitions for terms used in questions, differences in respondents' interpretation of questions, and recall/memory effects.

Other data collection methodologies (in-person interview, mailed questionnaire, or questions administered in "test" format in a school setting) may have had specific limitations. In-person interviews could result in either positive or negative response bias due to distractions posed by young children, especially when interview respondents simultaneously care for young children and answer questions. Other limitations include positive or negative response bias due to respondents' perceptions of a "correct" answer, question wording difficulties, lack of understanding of definitions of terms used, language and dialect differences between investigators and respondents, respondents' desires to avoid negative emotions associated with giving a particular type of answer, and respondent memory problems ("recall" effects) concerning past events. Mailed questionnaires have many of the same limitations as in-person interviews, but may allow respondents to respond when they are not distracted by childcare duties. An in-school test format is more problematic than either interviews or mailed surveys, because respondent bias related to teacher expectations could influence responses.

One approach to evaluating the degree of bias in survey response studies may be to make use of a surrogate biomarker indicator providing suggestive evidence of ingestion of significant quantities of soil (although quantitative estimates would not be possible). The biomarker technique measures the presence of serum antibodies to *Toxocara* species, a parasitic roundworm from cat and dog feces. Two U.S. studies have found associations between reported soil ingestion and positive serum antibody tests for *Toxocara* infection (Marmor et al., 1987; Glickman et al., 1981); a third (Nelson et al., 1996) has not, but the authors state that reliability of survey responses regarding soil ingestion may have been an issue. Further refinement of survey response methodologies, together with recent NHANES data on U.S. prevalence of positive serum antibody status regarding infection with *Toxocara* species, may be useful.

5.4.4. Key Studies: Representativeness of the U.S. Population

The two key studies of Dutch and Jamaican children may represent different conditions and different study populations than those in the United States; thus, it is unclear to what extent those children's soil ingestion behaviors may differ from U.S. children's soil ingestion behaviors. The subjects in the Davis and Mirick (2006) study may not have been representative of the general population since they were selected for their high compliance with the protocol from a previous study.

Limitations regarding the key studies performed in the United States for estimating soil and dust ingestion rates in the entire population of U.S. children ages 0 to <21 years fall into the broad categories of geographic range and demographics (age, sex, race/ethnicity, socioeconomic status).

Regarding geographic range, the two most obvious issues relate to soil types and climate. Soil properties might influence the soil ingestion estimates that are based on excreted tracer elements. The Davis et al. (1990); Calabrese et al. (1989); Barnes (1990); Davis and Mirick (2006); and Calabrese et al. (1997b) tracer element studies were in locations with soils that had sand content ranging from 21−80%, silt content ranging from 16−71%, and clay content ranging from 3−20% by weight, based on data from USDA (2008). The location of children in the Calabrese et al. (1997a) study was not specified, but due to the original survey response study's occurrence in western Massachusetts, the soil types in the vicinity of the Calabrese et al. (1997a) study are likely to be similar to those in the Calabrese et al. (1989) and Barnes (1990) study.

The Hogan et al. (1998) study included locations in the central part of the United States (an area along the Kansas/Missouri border, and an area in western Illinois) and one in the eastern United States (Palmerton, Pennsylvania). The only key study conducted in the southern part of the United States was Vermeer and Frate (1979).

Children might be outside and have access to soil in a very wide range of weather conditions (Wong et al., 2000). In the parts of the United States that experience moderate temperatures year-round, soil ingestion rates may be fairly evenly distributed throughout the year. During conditions of deep snow cover, extreme cold, or extreme heat, children could be expected to have minimal contact with outside soil. All children, regardless of location, could ingest soils located indoors in plant containers, soil derived particulates transported into dwellings as ambient airborne particulates, or outdoor soil tracked inside buildings by human or animal building occupants. Davis et al. (1990) did not find a clear or consistent association between the number of hours spent indoors per day and soil ingestion, but reported a consistent association between spending a greater number of hours outdoors and high (defined as the uppermost tertile) soil ingestion levels across all three tracers used.

The key tracer element studies all took place in northern latitudes. The temperature and precipitation patterns that occurred during these four studies' data collection periods were difficult to discern due to no mention of specific data collection dates in the published articles. The Calabrese et al. (1989) and Barnes (1990) study apparently took place in mid to late September 1987 in and near Amherst, Massachusetts; Calabrese et al. (1997b) apparently took place in late September and early October 1992, in Anaconda, Montana; Davis et al. (1990) took place in July, August, and September 1987, in Richland, Kennewick, and Pasco, Washington; and Davis and Mirick (2006) took place in the same Washington state location in late July, August, and very early September 1988 (raw data). Inferring exact data collection dates, a wide range of temperatures may have occurred during the four studies' data collection periods [daily lows from 22−60°F and 25−48°F, and daily highs from 53−81°F and 55−88°F in Calabrese et al. (1989) and Calabrese et al. (1997b), respectively, and daily lows from 51−72°F and 51−67°F, and daily highs from 69−103°F and 80−102°F in Davis et al. (1990) and Davis and Mirick (2006), respectively] (NCDC, 2008). Significant amounts of precipitation occurred during Calabrese et al. (1989) (more than 0.1 inches per 24-hour period) on several days; somewhat less precipitation was observed during Calabrese et al. (1997b); precipitation in Kennewick and Richland during the data collection periods of Davis et al. (1990) was almost non-existent; there was no recorded precipitation in Kennewick or Richland during the data collection period for Davis and Mirick (2006) (NCDC, 2008).

The key biokinetic model comparison study (Hogan et al., 1998) targeted three locations in more southerly latitudes (Pennsylvania, southern Illinois, and southern Kansas/Missouri) than the tracer element studies. The biokinetic model comparison methodology had an advantage over the tracer element studies in that the study represented long-term environmental exposures over periods up to several years that would include a range of seasons and climate conditions.

A brief review of the representativeness of the key studies' samples with respect to sex and age suggested that males and females were represented roughly equally in those studies for which study subjects' sex was stated. Children up to age 8 years were studied in seven of the nine studies, with an emphasis on younger children. Wong (1988); Calabrese and Stanek (1993); and Vermeer and Frate (1979) are the only studies with children 8 years or older.

A brief review of the representativeness of the key studies' samples with respect to socioeconomic status and racial/ethnic identity suggested that there were some discrepancies between the study subjects and the current U.S. population of children age 0 to <21 years. The single survey response study (Vermeer and Frate, 1979) was specifically targeted toward a predominantly rural Black population in a particular county in Mississippi. The tracer element studies are of predominantly White populations, apparently with limited representation from other racial and ethnic groups. The Amherst, Massachusetts study (Barnes, 1990; Calabrese et al., 1989) did not publish the study participants' socioeconomic status or racial and ethnic identities. The socioeconomic level of the Davis et al. (1990) studied children was reported to be primarily of middle to high income. Self-reported race and ethnicity of relatives of the children studied (in most cases, they were the parents of the children studied) in Davis et al. (1990) were White (86.5%), Asian (6.7%), Hispanic (4.8%), Native American (1.0%), and Other (1.0%), and the 91 married or living-as-married respondents identified their spouses as White (86.8%), Hispanic

(7.7%), Asian (4.4%), and Other (1.1%). Davis and Mirick (2006) did not state the race and ethnicity of the follow-up study participants, who were a subset of the original study participants from Davis et al. (1990). For the Calabrese et al. (1997b) study in Anaconda, Montana, population demographics were not presented in the published article. The study sample appeared to have been drawn from a door-to-door census of Anaconda residents that identified 642 toilet trained children who were less than 72 months of age. Of the 414 children participating in a companion study (out of the 642 eligible children identified), 271 had complete study data for that companion study, and of these 271, 97.4% were identified as White and the remaining 2.6% were identified as Native American, Black, Asian, and Hispanic (Hwang et al., 1997). The 64 children in the Calabrese et al. (1997b) study apparently were a stratified random sample (based on such factors as behavior during a previous study, the existence of a disability, or attendance in daycare) drawn from the 642 children identified in the door-to-door census. Presumably these children identified as similar races and ethnicities to the Hwang et al. (1997) study children. The Calabrese et al. (1997a) study indicated that 11 of the 12 children studied were White.

In summary, the geographic range of the key study populations was somewhat limited. Of those performed in the United States, locations included Massachusetts, Kansas, Montana, Missouri, Illinois, Washington, and Pennsylvania. The two most obvious issues regarding geographic range relate to soil types and climate. Soil types were not always described, so the representativeness of the key studies related to soil types and properties is unclear. The key tracer element studies all took place in northern latitudes. The only key study conducted in the southern part of the United States was Vermeer and Frate (1979).

In terms of sex and age, males and females were represented roughly equally in those studies for which study subjects' sex was stated, while the majority of children studied were under the age of eight. The tracer element studies are of predominantly White populations, with a single survey response study (Vermeer and Frate, 1979) targeted toward a rural Black population. Other racial and ethnic identities were not well reported among the key studies, nor was socioeconomic status. The socioeconomic level of the Davis et al. (1990) studied children was reported to be primarily of middle to high income.

5.5. SUMMARY OF SOIL AND DUST INGESTION ESTIMATES FROM KEY STUDIES

Table 5-22 summarizes the soil and dust ingestion estimates from the 12 key studies in chronological order. For the U.S. tracer element studies, in order to compare estimates that were calculated in a similar manner, the summary is limited to estimates that use the same basic algorithm of ([fecal and urine tracer content] - [food and medication tracer content])/[soil or dust tracer concentration]. Note that several of the published reanalyses suggest different variations on these algorithms, or suggest adjustments that should be made for various reasons (Calabrese and Stanek, 1995; Stanek and Calabrese, 1995b). Other reanalyses suggest that omitting some of the data according to statistical criteria would be a worthwhile exercise. Due to the current state of the science regarding soil and dust ingestion estimates, U.S. EPA does not advise omitting an individual's soil or dust ingestion estimate, based on statistical criteria, at this point in time.

There is a wide range of estimated soil and dust ingestion across key studies. Note that some of the soil-pica ingestion estimates from the tracer element studies were consistent with the estimated mean soil ingestion from the survey response study of geophagy behavior. The biokinetic model comparison methodology's confirmation of central tendency soil and dust ingestion default assumptions corresponded roughly with some of the central tendency tracer element study estimates. Also note that estimates based on the activity pattern methodology are comparable with estimates derived from the tracer element methodology.

5.6. DERIVATION OF RECOMMENDED SOIL AND DUST INGESTION VALUES

As stated earlier in this chapter, the key studies were used as the basis for developing the soil and dust ingestion recommendations shown in Table 5-1. The following sections describe in more detail how the recommended soil and dust ingestion values were derived.

5.6.1. Central Tendency Soil and Dust Ingestion Recommendations

For the central tendency recommendations shown in Table 5-1, Van Wïjnen et al. (1990) published soil ingestion "LTM" estimates based on infants older than 6 weeks but less than 1 year old (exact ages unspecified). During "bad" weather (>4 days per week of precipitation), the geometric mean estimated LTM values were 67 and 94 milligrams soil (dry weight)/day; during "good" weather (<2 days/week of precipitation) the geometric mean estimated LTM values were 102 milligrams soil (dry weight)/day (van Wijnen et al., 1990). These values were not corrected to exclude dietary intake of the tracers on which they were based. The developers of the IEUBK model used these data as the basis for the default soil and dust intakes for the 6 to <12 month old infants in the IEUBK model (U.S. EPA, 1994b) of 38.25 milligrams soil/day and 46.75 mg house dust/day, for a total soil + dust intake default assumption of 85 mg/day for this age group (U.S. EPA, 1994a).

Further evidence of dust intake by infants has been conducted in the context of evaluating blood lead levels and the potential contributions of lead from three sources: bone turnover, food sources, and environmental exposures such as house dust. Manton et al. (2000) conducted a study with older infants and young children, and concluded that appreciable quantities of dust were ingested by infants. Gulson et al. (2001) studied younger infants than Manton et al. (2000) and did not explicitly include dust sources, but the authors acknowledged that, based on ratios of different isotopes of lead found in infants' blood and urine, there appeared to be a non-food, non-bone source of lead of environmental origin that contributed "minimally," relative to food intakes and bone turnover in 0- to 6-month-old infants.

The Hogan et al. (1998) data for 38 infants (one group $N = 7$ and one group $N = 31$) indicated that the IEUBK default soil and dust estimate for 6 to <12 month olds (85 mg/day) over-predicted blood lead levels in this group, suggesting that applying an 85 mg soil + dust (38 mg soil + 47 mg house dust) per day estimate for 6 months' exposure may be too high for this life stage.

For the larger of two groups of infants aged 6 to <12 months in the Hogan et al. (1998) study ($N = 31$), the default IEUBK value of 85 mg/day predicted geometric mean blood lead levels of 5.2 µg/dL versus 3.8 µg/dL actual measured blood lead level (a ratio of 1.37). It is possible that the other major sources of lead accounted for in the IEUBK model (dietary and drinking water lead) are responsible for part of the over-prediction seen with the Hogan et al. (1998) study. Rounded to the ones place, the default assumed daily lead intakes were (dietary) 6 µg/day and (drinking water) 1 µg/day, compared to the soil lead intake of 8 µg/day and house dust lead intake of 9 µg/day (U.S. EPA, 1994b). The dietary lead intake default assumption thus might be expected to be responsible for the over-predictions as well as the soil and dust intake, since these three sources (diet, soil, and dust) comprise the majority of the total lead intake in the model. Data from Manton et al. (2000) suggest that the default assumption for dietary lead intake might be somewhat high (reported geometric mean daily lead intake from food in Manton et al. (2000) was 3.2 µg/day, arithmetic mean 3.3 µg/day).

Making use of the epidemiologic data from the larger group of 31 infants in the Hogan et al. (1998) study, it is possible to develop an extremely rough estimate of soil + dust intake by infants 6 weeks to <12 months of age. The ratio of the geometric mean IEUBK-predicted to actual measured blood lead levels in 31 infants was 1.37. This value may be used to adjust the soil and dust intake rate for the 6 to <12 month age range. Using the inverse of 1.37 (0.73) and multiplying the 85 mg/day soil + house dust intake rate by this value, gives an adjusted value of 62 mg/day soil + dust, rounded to one significant figure at 60 mg/day. The 38 mg soil/day intake rate, multiplied by the 0.73 adjustment factor, yields 28 mg soil per day (rounding to 30 mg soil per day); the 47 mg house dust/day intake rate multiplied by 0.73 yields 34 mg house dust per day (rounding to 30 mg house dust per day). These values, adjusted from the IEUBK default values, are the basis for the soil (30 mg/day) and dust (30 mg/day) recommendations for children aged 6 weeks to 12 months.

For children age 1 to <6 years, the IEUBK default values used in the Hogan et al. (1998) study were: 135 mg/day for 1, 2, and 3 year olds; 100 mg/day for 4 year olds; 90 mg/day for 5 year olds; and 85 mg/day for 6 year olds. These values were based on an assumption of 45% soil, 55% dust (U.S. EPA, 1994a). The time-averaged daily soil + dust ingestion rate for these 6 years of life is 113 mg/day, dry-weight basis. The Hogan et al. (1998) study found the following over- and under-predictions of blood lead levels, compared to actual measured blood lead levels, using the default values shown in Table 5-23. Apportioning the 113 mg/day, on average, into 45% soil and 55% dust (U.S. EPA, 1994a), yields an average for this age group of 51 mg/day soil, 62 mg/day dust. Rounded to one significant figure, these values are 50 and 60 mg/day, respectively. The 60 mg/day dust would be comprised of a combination of outdoor soil tracked indoors onto floors, indoor dust on floors, indoor settled dust on non-floor surfaces, and probably a certain amount of inhaled suspended dust that is swallowed and enters the gastrointestinal tract. Soil ingestion rates were assumed to be comparable for children age 1 to <6 years and 6 to <21 years, and therefore the same recommended values were used for both age groups. Estimates derived by Özkaynak et al. (2011) suggest soil and dust ingestion rates comparable to other estimates in the literature based on tracer element methodology (i.e., a mean value of 68 mg/day).

The recommended soil and dust ingestion rate of 50 mg/day for adults was taken from the overall mean value of 52 mg/day for the adults in the Davis and Mirick (2006) study. Based on this value, the recommended adult soil and dust ingestion value is estimated to be 50 mg/day. There are no available studies estimating the ingestion of dust by adults, therefore, the recommended values for soil and dust were derived from the soil + dust ingestion, assuming 45% soil and 55% dust contribution.

5.6.2. Upper Percentile, Soil Pica, and Geophagy Recommendations

Upper percentile estimates for children 3 to <6 years old were derived from Özkaynak et al. (2011) and Stanek and Calabrese (1995b). These two studies had similar estimates of 95th percentile value (i.e., 224 mg/day and 207 mg/day, respectively). Rounding to one significant figure, the recommended upper percentile estimate of soil and dust ingestion is 200 mg/day. Soil and dust ingestion recommendations were obtained from Özkaynak et al. (2011). For the upper percentile soil pica and geophagy recommendations shown in Table 5-1, two primary lines of evidence suggest that at least some U.S. children exhibit soil-pica behavior at least once during childhood. First, the survey response studies of reported soil ingestion behavior that were conducted in numerous U.S. locations and of different populations consistently yield a certain proportion of respondents who acknowledge soil ingestion by children. The surveys typically did not ask explicit and detailed questions about the soil ingestion incidents reported by the care givers who acknowledged soil ingestion in children. Responses conceivably could fall into three categories: (1) responses in which care givers interpret visible dirt on children's hands, and subsequent hand-to-mouth behavior, as soil ingestion; (2) responses in which care givers interpret intentional ingestion of clay, "dirt" or soil as soil ingestion; and (3) responses in which care givers regard observations of hand-to-mouth behavior of visible quantities of soil as soil ingestion. Knowledge of soils' bulk density allows inferences to be made that these latter observed hand-to-mouth soil ingestion incidents are likely to represent a quantity of soil that meets the quantity part of the definition of soil-pica used in this chapter, or 1,000 mg. Occasionally, what is not known from survey response studies is whether the latter type of survey responses include responses regarding repeated soil ingestion that meets the definition of soil-pica used in this chapter. The second category probably does represent ingestion that would satisfy the definition of soil-pica as well as geophagy. The first category may represent relatively small amounts that appear to be ingested by many children based on the Hogan et al. (1998) study and the tracer element studies. Second, the U.S. tracer studies report a wide range of soil ingestion values. Due to averaging procedures used, for 4, 7, or 8 day periods, the rounded range of these estimates of soil ingestion behavior that apparently met the definition of soil-pica used in this chapter is from 400 to 41,000 mg/day. The recommendation of 1,000 mg/day for soil-pica is based on this range.

Although there were no tracer element studies or biokinetic model comparison studies performed for children 15 to <21 years, in which soil-pica behavior of children in this age range has been investigated, U.S. EPA is aware of one study documenting pica behavior in a group that includes children in this age range (Hyman et al., 1990). The study was not specific regarding whether soil-pica (versus other pica substances) was observed, nor did it identify the specific ages of the children observed to practice pica. In the absence of data that can be used to develop specific soil-pica soil ingestion recommendations for children aged 15 years and 16 to <21 years, U.S. EPA recommends that risk assessors who need to assess risks via soil and dust ingestion to children ages 15 to <21 years use the same soil ingestion rate as that recommended for younger children, in the 1 to <6, 6 to <11, and 11 to <16 year old age categories.

Researchers who have studied human geophagy behavior around the world typically have studied populations in specific locations, and often include investigations of soil properties as part of the research (Wilson, 2003; Aufreiter et al., 1997). Most studies of geophagy behavior in the United States were survey response studies of residents in specific locations who acknowledged eating clays. Typically, study subjects were from a relatively small area such as a county, or a group of counties within the same state. Although geophagy behavior may have been studied in only a single county in a given state, documentation of geophagy behavior by some residents in one or more counties of a given state may suggest that the same behavior also occurs elsewhere within that state.

A qualitative description of amounts of soil ingested by geophagy practitioners was provided by Vermeer and Frate (1979) with an estimated mean amount, 50 g/day, that apparently was averaged over 32 adults and 18 children. The 18 children whose caregivers acknowledged geophagy (or more specifically, eating of clay) were (*N* = 16) ages 1 to 4 and (*N* = 2) ages 5 to 12 years. The definition of geophagy used included consumption of clay "on a regular basis over a period of weeks." U.S. EPA is recommending this 50 g/day value for geophagy. This mean quantity is roughly consistent with a median quantity reported by Geissler et al. (1998) in a survey response study of geophagy in primary school children in Nyanza Province, Kenya (28 g/day, range 8 to 108 g/day; interquartile range 13 to 42 g/day).

Recent studies of pica among pregnant women in various U.S. locations (Corbett et al., 2003; Rainville, 1998; Smulian et al., 1995) suggest that clay geophagy among pregnant women may include children less than 21 years old (Corbett et al., 2003; Smulian et al., 1995). Smulian provides a quantitative estimate of clay consumption of approximately 200−500 g/week, for the very small number of geophagy practitioners (*N* = 4) in that study's sample (*N* = 125). If consumed on a daily basis, this quantity (approximately 30 to 70 g/day) is roughly consistent with the Vermeer and Frate (1979) estimated mean of 50 g/day.

Johns and Duquette (1991) describe use of clays in baking bread made from acorn flour, in a ratio of 1 part clay to 10 or 20 parts acorn flour, by volume, in a Native American population in California, and in Sardinia (~12 grams clay suspended in water added to 100 grams acorn). Either preparation method would add several grams of clay to the final prepared food; daily ingestion of the food would amount to several grams of clay ingested daily.

5.7. REFERENCES FOR CHAPTER 5

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Table 5-3. Soil, Dust, and Soil + Dust Ingestion Estimates for Amherst, Massachusetts Study Children

Tracer Element	*N*	Ingestion (mg/day)				
		Mean	Median	SD	95th Percentile	Maximum
Aluminum						
soil	64	153	29	852	223	6,837
dust	64	317	31	1,272	506	8,462
soil/dust combined	64	154	30	629	478	4,929
Barium						
soil	64	32	–37	1,002	283	6,773
dust	64	31	–18	860	337	5,480
soil/dust combined	64	29	–19	868	331	5,626
Manganese						
soil	64	–294	–261	1,266	788	7,281
dust	64	–1,289	–340	9,087	2,916	20,575
soil/dust combined	64	–496	–340	1,974	3,174	4,189
Silicon						
soil	64	154	40	693	276	5,549
dust	64	964	49	6,848	692	54,870
soil/dust combined	64	483	49	3,105	653	24,900
Vanadium						
soil	62	459	96	1,037	1,903	5,676
dust	64	453	127	1,005	1,918	6,782
soil//dust combined	62	456	123	1,013	1,783	6,736
Yttrium						
soil	62	85	9	890	106	6,736
dust	64	62	15	687	169	5,096
soil/dust combined	62	65	11	717	159	5,269
Zirconium						
soil	62	21	16	209	110	1,391
dust	64	27	12	133	160	789
soil/dust combined	62	23	11	138	159	838
Titanium						
soil	64	218	55	1,150	1,432	6,707
dust	64	163	28	659	1,266	3,354
soil/dust combined	64	170	30	691	1,059	3,597

SD = Standard deviation.
N = Number of subjects.

Source: Calabrese et al. (1989).

Table 5-4. Amherst, Massachusetts Soil-Pica Child's Daily Ingestion Estimates by Tracer and by Week (mg/day)

Tracer element	Estimated Soil Ingestion (mg/day) Week 1	Week 2
Al	74	13,600
Ba	458	12,088
Mn	2,221	12,341
Si	142	10,955
Ti	1,543	11,870
V	1,269	10,071
Y	147	13,325
Zr	86	2,695

Source: Calabrese et al. (1991).

Table 5-5. Van Wijnen et al. (1990) Limiting Tracer Method (LTM) Soil Ingestion Estimates for Sample of Dutch Children

Age (years)	Sex	Daycare Center *N*	Daycare Center GM LTM (mg/day)	Daycare Center GSD LTM (mg/day)	Campground *N*	Campground GM LTM (mg/day)	Campground GSD LTM (mg/day)
Birth to <1	Girls	3	81	1.09	NA	NA	NA
	Boys	1	75		NA	NA	NA
1 to <2	Girls	20	124	1.87	3	207	1.99
	Boys	17	114	1.47	5	312	2.58
2 to <3	Girls	34	118	1.74	4	367	2.44
	Boys	17	96	1.53	8	232	2.15
3 to <4	Girls	26	111	1.57	6	164	1.27
	Boys	29	110	1.32	8	148	1.42
4 to <5	Girls	1	180		19	164	1.48
	Boys	4	99	1.62	18	136	1.30
All girls		86	117	1.70	36	179	1.67
All boys		72	104	1.46	42	169	1.79
Total		162[a]	111	1.60	78[b]	174	1.73

[a] Age and/or sex not registered for 8 children; one untransformed value = 0.
[b] Age not registered for 7 children; geometric mean LTM value = 140.
N = Number of subjects.
GM = Geometric mean.
LTM = Limiting tracer method.
GSD = Geometric standard deviation.
NA = Not available.

Source: Adapted from Van Wijnen et al. (1990).

Table 5-6. Estimated Geometric Mean Limiting Tracer Method (LTM) Soil Ingestion Values of Children Attending Daycare Centers According to Age, Weather Category, and Sampling Period

Weather Category	Age (years)	First Sampling Period		Second Sampling Period	
		N	Estimated Geometric Mean LTM Value (mg/day)	*N*	Estimated Geometric Mean LTM Value (mg/day)
Bad	<1	3	94	3	67
(>4 days/week	1 to <2	18	103	33	80
precipitation)	2 to <3	33	109	48	91
	4 to <5	5	124	6	109
Reasonable	<1			1	61
(2−3 days/week	1 to <2			10	96
precipitation)	2 to <3			13	99
	3 to <4			19	94
	4 to <5			1	61
Good	<1	4	102		
(<2 days/week	1 to <2	42	229		
precipitation)	2 to <3	65	166		
	3 to <4	67	138		
	4 to <5	10	132		

N = Number of subjects.
LTM = Limiting tracer method.

Source: Van Wijnen et al. (1990).

Table 5-7. Estimated Soil Ingestion for Sample of Washington State Children[a]

Element	Mean (mg/day)	Median (mg/day)	Standard Error of the Mean (mg/day)	Range (mg/day)[b]
Aluminum	38.9	25.3	14.4	–279.0 to 904.5
Silicon	82.4	59.4	12.2	–404.0 to 534.6
Titanium	245.5	81.3	119.7	–5,820.8 to 6,182.2
Minimum	38.9	25.3	12.2	–5,820.8
Maximum	245.5	81.3	119.7	6,182.2

[a] Excludes three children who did not provide any samples (*N* = 101).
[b] Negative values occurred as a result of correction for non-soil sources of the tracer elements. For aluminum, lower end of range published as 279.0 mg/day in article appears to be a typographical error that omitted the negative sign.

Source: Adapted from Davis et al. (1990).

Table 5-8. Soil Ingestion Estimates for 64 Anaconda Children

Tracer	Estimated Soil Ingestion (mg/day)							
	p1	p50	p75	p90	p95	Max	Mean	SD
Al	–202.8	–3.3	17.7	66.6	94.3	461.1	2.7	95.8
Ce	–219.8	44.9	164.6	424.7	455.8	862.2	116.9	186.1
La	–10,673	84.5	247.9	460.8	639.0	1,089.7	8.6	1,377.2
Nd	–387.2	220.1	410.5	812.6	875.2	993.5	269.6	304.8
Si	–128.8	–18.2	1.4	36.9	68.9	262.3	–16.5	57.3
Ti	–15,736	11.9	398.2	1,237.9	1,377.8	4,066.6	–544.4	2,509.0
Y	–441.3	32.1	85.0	200.6	242.6	299.3	42.3	113.7
Zr	–298.3	–30.8	17.7	94.6	122.8	376.1	–19.6	92.5
BTM soil	NA	20.1	68.9	223.6	282.4	609.9	65.5	120.3
BTM dust	NA	26.8	198.1	558.6	613.6	1,499.4	127.2	299.1

p = Percentile.
SD = Standard deviation.
BTM = Best Tracer Methodology.
NA Not available.
Note: Negative values are a result of limitations in the methodology.

Source: Calabrese et al. (1997b).

Table 5-9. Soil Ingestion Estimates for Massachusetts Children Displaying Soil Pica Behavior (mg/day)

Study day	Al-based estimate	Si-based estimate	Ti-based estimate
1	53	9	153
2	7,253	2,704	5,437
3	2,755	1,841	2,007
4	725	534	801
5	5	–10	21
6	1,452	1,373	794
7	238	76	84

Note: Negative values are a result of limitations in the methodology.

Source: Calabrese et al. (1997a).

Table 5-10. Average Daily Soil and Dust Ingestion Estimate (mg/day)

Type of Estimate	Soil Ingestion			Dust Ingestion		
	Al	Si	Ti	Al	Si	Ti
Mean	168	89	448	260	297	415
Median	7	0	32	13	2	66
SD	510	270	1,056	759	907	1,032
Range	–15 to +1,783	–46 to +931	–47 to +3,581	–39 to +2,652	–351 to +3,145	–98 to +3,632

SD = Standard deviation.
Note: Negative values are a result of limitations in the methodology.

Source: Calabrese et al. (1997a).

Table 5-11. Mean and Median Soil Ingestion (mg/day) by Family Member

Participant	Tracer Element	Estimated Soil Ingestion[a] (mg/day)			Maximum
		Mean	Median	SD	
Child[b]	Aluminum	36.7	33.3	35.4	107.9
	Silicon	38.1	26.4	31.4	95.0
	Titanium	206.9	46.7	277.5	808.3
Mother[c]	Aluminum	92.1	0	218.3	813.6
	Silicon	23.2	5.2	37.0	138.1
	Titanium	359.0	259.5	421.5	1,394.3
Father[d]	Aluminum	68.4	23.2	129.9	537.4
	Silicon	26.1	0.2	49.0	196.8
	Titanium	624.9	198.7	835.0	2,899.1

[a] For some study participants, estimated soil ingestion resulted in a negative value. These estimates have been set to 0 mg/day for tabulation and analysis.
[b] Results based on 12 children with complete food, excreta, and soil data.
[c] Results based on 16 mothers with complete food, excreta, and soil data.
[d] Results based on 17 fathers with complete food, excreta, and soil data.
SD = Standard deviation.

Source: Davis and Mirick (2006).

Table 5-12. Estimated Soil Ingestion for Six High Soil Ingesting Jamaican Children

Child	Month	Estimated soil ingestion (mg/day)
11	1	55
	2	1,447
	3	22
	4	40
12	1	0
	2	0
	3	7,924
	4	192
14	1	1,016
	2	464
	3	2,690
	4	898
18	1	30
	2	10,343
	3	4,222
	4	1,404
22	1	0
	2	-
	3	5,341
	4	0
27	1	48,314
	2	60,692
	3	51,422
	4	3,782

- = No data.

Source: Calabrese and Stanek (1993).

Table 5-13. Positive/Negative Error (bias) in Soil Ingestion Estimates in Calabrese et al. (1989) Study: Effect on Mean Soil Ingestion Estimate (mg/day)[a]

Tracer	Negative Error						
	Lack of Fecal Sample on Final Study Day	Other Cause[b]	Total Negative Error	Total Positive Error	Net Error	Original Mean	Adjusted Mean
Aluminum	14	11	25	43	+18	153	136
Silicon	15	6	21	41	+20	154	133
Titanium	82	187	269	282	+13	218	208
Vanadium	66	55	121	432	+311	459	148
Yttrium	8	26	34	22	–12	85	97
Zirconium	6	91	97	5	–92	21	113

[a] How to read table: for example, aluminum as a soil tracer displayed both negative and positive error. The cumulative total negative error is estimated to bias the mean estimate by 25 mg/day downward. However, aluminum has positive error biasing the original mean upward by 43 mg/day. The net bias in the original mean was 18 mg/day positive bias. Thus, the original 156 mg/day mean for aluminum should be corrected downward to 136 mg/day.

[b] Values indicate impact on mean of 128-subject-weeks in milligrams of soil ingested per day.

Source: Calabrese and Stanek (1995).

Table 5-14. Predicted Soil and Dust Ingestion Rates for Children Age 3 to <6 Years (mg/day)

		Mean	Percentile					
			5	25	50	75	95	100
Dust ingestion/hand-to-mouth	1,000	19.8	0.6	3.4	8.4	21.3	73.7	649.3
Dust ingestion/ object-to-mouth	1,000	6.9	0.1	0.7	2.4	7.4	27.2	252.7
Total dust ingestion[a]	1,000	27			13		109	360
Soil ingestion/hand-to-mouth	1,000	41.0	0.2	5.3	15.3	44.9	175.6	1,367.4
Total ingestion	1,000	67.6	4.9	16.8	37.8	83.2	224.0	1,369.7

[a] Email from Haluk Özkaynak (NERL, U.S. EPA) to Jacqueline Moya (NCEA, EPA) dated 3/8/11.

Source: Özkaynak et al. (2011).

Table 5-15. Estimated Daily Soil Ingestion for East Helena, Montana Children

Estimation Method	Mean (mg/day)	Median (mg/day)	Standard Deviation (mg/day)	Range (mg/day)	95th Percentile (mg/day)	Geometric Mean (mg/day)
Aluminum	181	121	203	25−1,324	584	128
Silicon	184	136	175	31−799	578	130
Titanium	1,834	618	3,091	4−17,076	9,590	401
Minimum	108	88	121	4−708	386	65

Source: Binder et al. (1986).

Table 5-16. Estimated Soil Ingestion for Sample of Dutch Nursery School Children

Child	Sample Number	Soil Ingestion as Calculated from Ti (mg/day)	Soil Ingestion as Calculated from Al (mg/day)	Soil Ingestion as Calculated from AIR (mg/day)	Limiting Tracer (mg/day)
1	L3	103	300	107	103
	L14	154	211	172	154
	L25	130	23	-	23
2	L5	131	-	71	71
	L13	184	103	82	82
	L27	142	81	84	81
3	L2	124	42	84	42
	L17	670	566	174	174
4	L4	246	62	145	62
	L11	2,990	65	139	65
5	L8	293	-	108	108
	L21	313	-	152	152
6	L12	1,110	693	362	362
	L16	176	-	145	145
7	L18	11,620	-	120	120
	L22	11,320	77	-	77
8	L1	3,060	82	96	82
9	L6	624	979	111	111
10	L7	600	200	124	124
11	L9	133	-	95	95
12	L10	354	195	106	106
13	L15	2,400	-	48	48
14	L19	124	71	93	71
15	L20	269	212	274	212
16	L23	1,130	51	84	51
17	L24	64	566	-	64
18	L26	184	56	-	56
Arithmetic Mean		1,431	232	129	105

- = No data.
AIR = Acid insoluble residue.

Source: Adapted from Clausing et al. (1987).

Table 5-17. Estimated Soil Ingestion for Sample of Dutch Hospitalized, Bedridden Children

Child	Sample	Soil Ingestion as Calculated from Ti (mg/day)	Soil Ingestion as Calculated from Al (mg/day)	Limiting Tracer (mg/day)
1	G5	3,290	57	57
	G6	4,790	71	71
2	G1	28	26	26
3	G2	6,570	94	84
	G8	2,480	57	57
4	G3	28	77	28
5	G4	1,100	30	30
6	G7	58	38	38
Arithmetic Mean		2,293	56	49

Source: Adapted from Clausing et al. (1987).

Table 5-18. Items Ingested by Low-Income Mexican-Born Women Who Practiced Pica During Pregnancy in the United States (*N* = 46)

Item Ingested	Number (%) Ingesting Items
Dirt	11 (24)
Bean stones[a]	17 (37)
Magnesium carbonate	8 (17)
Ashes	5 (11)
Clay	4 (9)
Ice	18 (39)
Other[b]	17 (37)

[a] Little clods of dirt found among unwashed beans.
[b] Including eggshells, starch, paper, lipstick, pieces of clay pot, and adobe.
N = Number of individuals reporting pica behavior.

Source: Simpson et al. (2000).

Table 5-19. Distribution of Average (mean) Daily Soil Ingestion Estimates per Child for 64 Children[a] (mg/day)

Type of Estimate	Overall	Al	Ba	Mn	Si	Ti	V	Y	Zr
Number of Samples	64	64	33	19	63	56	52	61	62
Mean	179	122	655	1,053	139	271	112	165	23
25th Percentile	10	10	28	35	5	8	8	0	0
50th Percentile	45	19	65	121	32	31	47	15	15
75th Percentile	88	73	260	319	94	93	177	47	41
90th Percentile	186	131	470	478	206	154	340	105	87
95th Percentile	208	254	518	17,374	224	279	398	144	117
Maximum	7,703	4,692	17,991	17,374	4,975	12,055	845	8,976	208

[a] For each child, estimates of soil ingestion were formed on days 4–8 and the mean of these estimates was then evaluated for each child. The values in the column "overall" correspond to percentiles of the distribution of these means over the 64 children. When specific trace elements were not excluded via the relative standard deviation criteria, estimates of soil ingestion based on the specific trace element were formed for 108 days for each subject. The mean soil ingestion estimate was again evaluated. The distribution of these means for specific trace elements is shown.

Source: Stanek and Calabrese (1995a).

Table 5-20. Estimated Distribution of Individual Mean Daily Soil Ingestion Based on Data for 64 Subjects Projected Over 365 Days[a]	
Range	1−2,268 mg/day[b]
50th Percentile (median)	75 mg/day
90th Percentile	1,190 mg/day
95th Percentile	1,751 mg/day

[a] Based on fitting a lognormal distribution to model daily soil ingestion values.
[b] Subject with pica excluded.

Source: Stanek and Calabrese (1995a).

Table 5-21. Prevalence of Non-Food Consumption by Substance for NHANES I and NHANES II

	NHANES I (age 1−74 years) *N* (sample size) = 20,724 (unweighted); 193,716,939 (weighted)			NHANES II (age 6 months−74 years) *N* (sample size) = 25,271 (unweighted); 203,432,944 (weighted)		
Substance	*N* Unweighted (Weighted)	Prevalence[a]	95% Confidence Interval	*N* Unweighted (Weighted)	Prevalence[a]	95% Confidence Interval
Any Non-Food Substance	732 (4,900,370)	2.5%	2.2−2.9%	480 (2,237,993)	1.1%	1.0−1.2%
Clay				46 (223,361)	0.1%	0.1−0.2%
Starch	131 (582,101)	0.3%	0.2−0.4%	61 (450,915)	0.2%	0.1−0.3%
Paint and Plaster	39 (195,764)	0.5%[b]	0.3−0.7%	55 (213,588)	0.6%[c]	0.4−0.8%
Dirt				216 (772,714)	2.1%[d]	1.7−2.5%
Dirt and Clay	385 (2,466,210)	1.3%	1.1−1.5%			
Other	190 (1,488,327)	0.8%	0.6−0.9%	218 (1,008,476)	0.5%	0.4−0.6%

Unweighted = Raw counts.
Weighted = Adjusted to account for the unequal selection probabilities caused by the cluster design, item non-response, and planned oversampling of certain subgroups, and representative of the civilian non-institutionalized Census population in the coterminous United States.
[a] Prevalence = Frequency (*n*) (weighted)/Sample Size (*N*) (weighted).
[b] NHANES I sample size (<12 years): 4,968 (unweighted); 40,463,951 (weighted).
[c] NHANES II sample size (<12 years): 6,834 (unweighted); 37,697,059 (weighted).
[d] For those aged <12 years only; question not prompted for those ≥12 years.

Source: Gavrelis et al. (2011).

Table 5-22. Summary of Estimates of Soil and Dust Ingestion by Adults and Children (0.5 to 14 years old) From Key Studies (mg/day)

Sample Size	Age (year)	Ingestion medium	Mean	p25	p50	p75	p90	p95	Reference
140	1 to13+	Soil	50,000[a]	NR	NR	NR	NR	NR	Vermeer and Frate (1979)
89	Adult	Soil	50,000[a]	NR	NR	NR	NR	NR	Vermeer and Frate (1979)
52	0.3 to14	Soil	NR	NR	NR	NR	~1,267	~4,000	Wong (1988); Calabrese and Stanek (1993)
64	1 to <4	Soil	−294 to +459	NR	−261 to +96	NR	67 to 1,366	106 to 1,903	Calabrese et al. (1989)
		Dust	−1,289 to +964	NR	−340 to +127	NR	91 to 1,700	160 to 2,916	
		Soil and Dust	−496 to +483	NR	−340 to +456	NR	89 to 1,701	159 to 3,174	
292	0.1 to <1	Soil	0 to 30[b]	NR	NR	NR	NR	NR	Van Wijnen et al. (1990)
	1 to <5	Soil	0 to 200[b]	NR	NR	NR	≤300	NR	
101	2 to <8	Soil	39 to 246	NR	25 to 81	NR	NR	NR	Davis et al. (1990)
		Soil and Dust	65 to 268	NR	52 to 117	NR	NR	NR	
64	1 to <4	Soil	97 to 208	NR	NR	NR	NR	NR	Calabrese and Stanek (1995)
165	1 to <8	Soil	104	NR	37	NR	NR	217	Stanek and Calabrese (1995b)
64	1 to <4	Soil	−544 to +270	−582to +65	−31 to +220	1 to 411	37 to 1,238	69 to 1,378	Calabrese et al. (1997b)
478	<1 to <7	Soil and Dust	113	NR	NR	NR	NR	NR	Hogan et al. (1998)
33	Adult	Soil	23 to 625	NR	0 to 260	NR	NR	138 to 2,899	Davis and Mirick (2006)
12	3 to <8	Soil	37 to 207	NR	26 to 47	NR	NR	95 to 808	Davis and Mirick (2006)
1,000[c]	3 to <6	Soil	41	5.3	15.3	44.9	NR	175.6	Özkaynak et al. (2011)
		Dust	27	NR	13	NR	NR	109	
		Soil and Dust	68	16.8	37.8	83.2	NR	224	

a Average includes adults and children.
b Geometric mean.
c Simulated.
NR = Not reported.
p = Percentile.

Table 5-23. Comparison of Hogan et al. (1998) Study Subjects' Predicted Blood Lead Levels With Actual Measured Blood Lead Levels, and Default Soil + Dust Intakes Used in IEUBK Modeling

Age (year)	*N*	*N* prediction >actual	*N* prediction <actual	time-averaged default soil + dust intake (mg/day)
1 and 2	164	14	150	135
3 and 4	142	104	38	117.5
5 and 6	134	0	134	87.5
Average				113

N = Number.

Source: Adapted from Hogan et al. (1998).

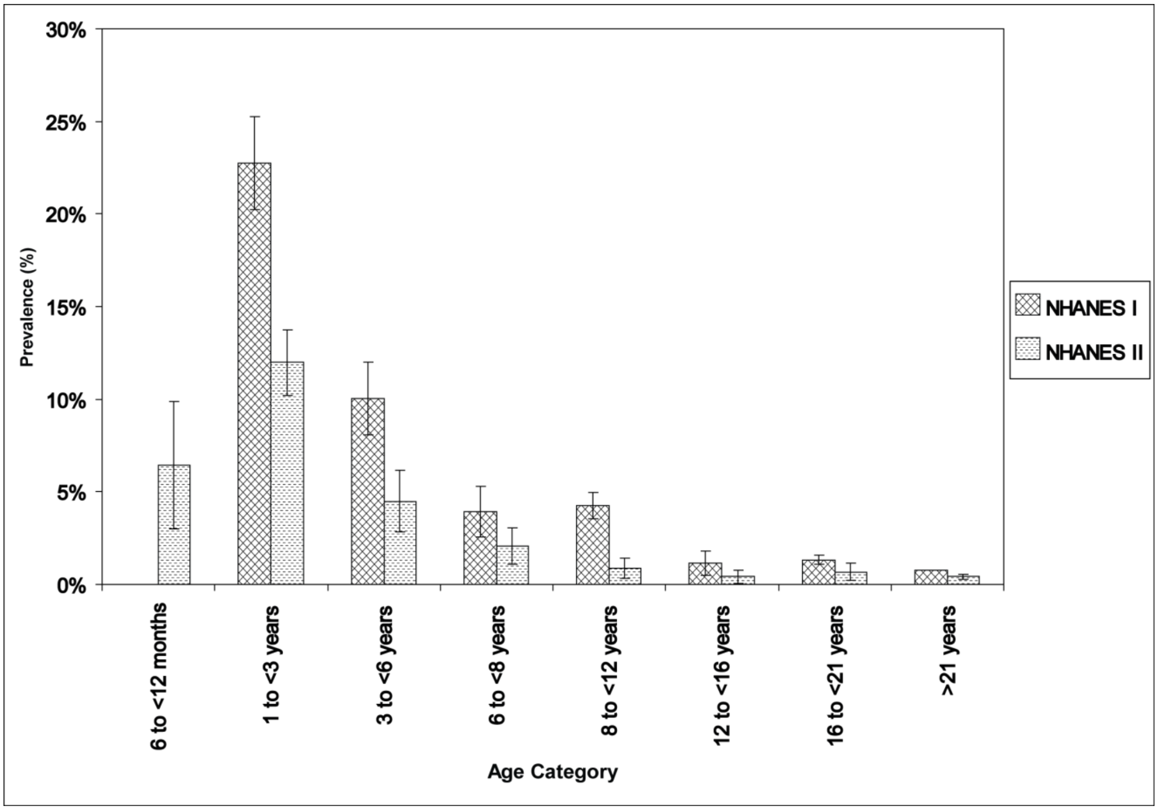

Figure 5-1. Prevalence of Non-Food Substance Consumption by Age, NHANES I and NHANES II.

Source: Gavrelis et al. (2011).

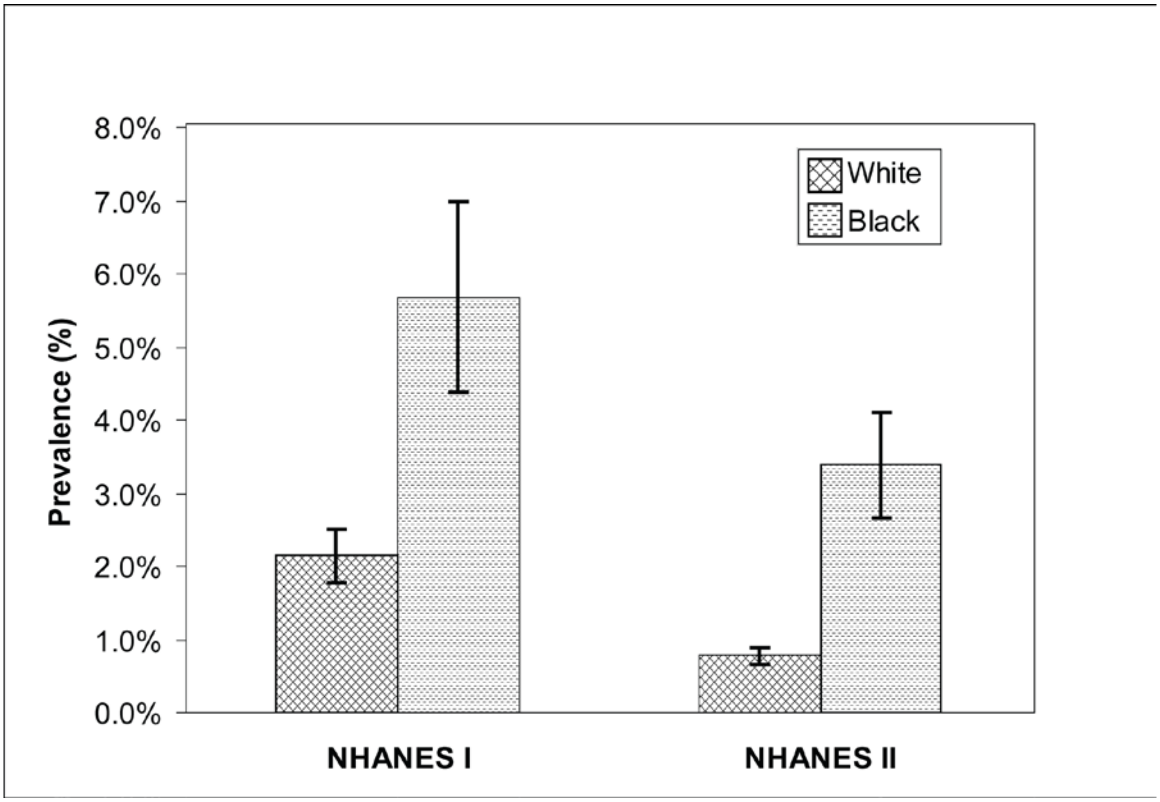

Figure 5-2. Prevalence of Non-Food Substance Consumption by Race, NHANES I and NHANES II.

Source: Gavrelis et al. (2011).

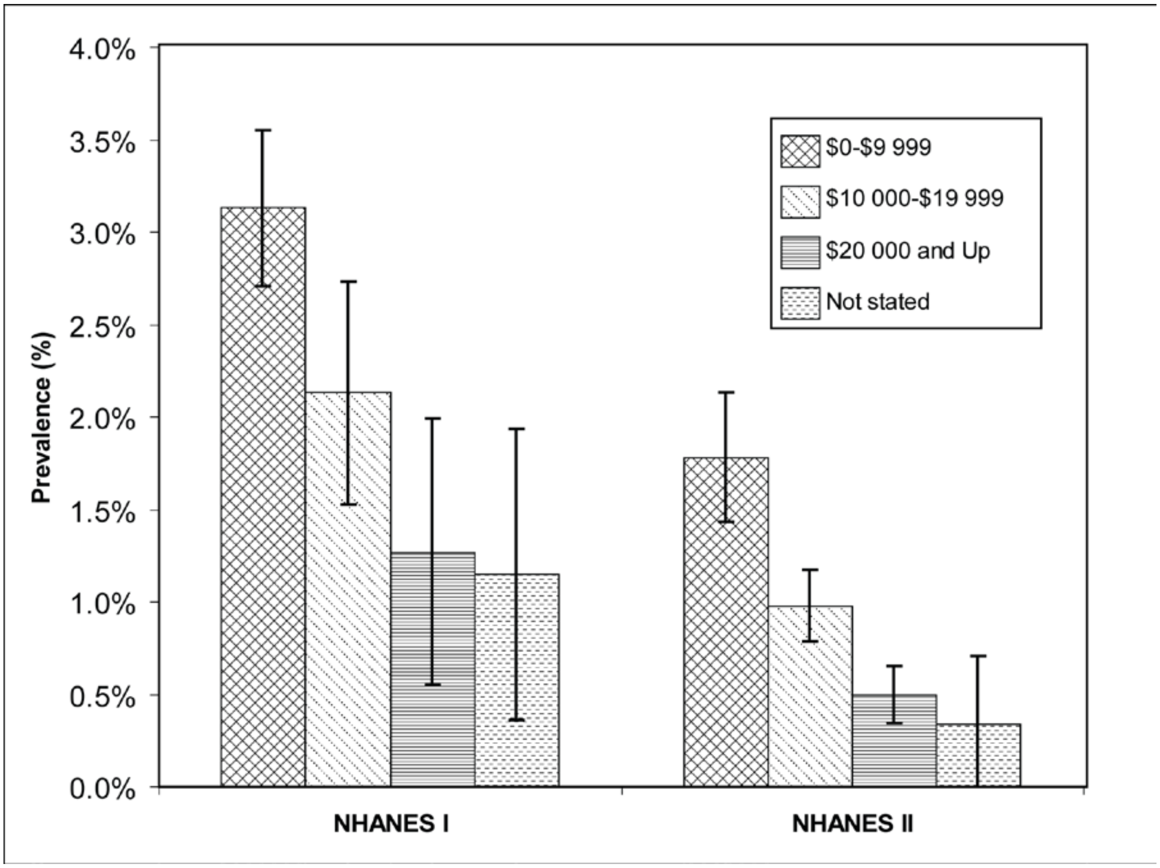

Figure 5-3. Prevalence of Non-Food Substance Consumption by Income, NHANES I and NHANES II.

Source: Gavrelis et al. (2011).

6. INHALATION RATES

6.1. INTRODUCTION

Ambient and indoor air are potential sources of exposure to toxic substances. Adults and children can be exposed to contaminated air during a variety of activities in different environments. They may be exposed to contaminants in ambient air and may also inhale chemicals from the indoor use of various sources (e.g., stoves, heaters, fireplaces, and consumer products) as well as from those that infiltrate from ambient air.

The Agency defines exposure as the chemical concentration at the boundary of the body (U.S. EPA, 1992). In the case of inhalation, the situation is complicated by the fact that oxygen exchange with carbon dioxide takes place in the distal portion of the lung. The anatomy and physiology of the respiratory system as well as the characteristics of the inhaled agent diminishes the pollutant concentration in inspired air (potential dose) such that the amount of a pollutant that actually enters the body through the upper respiratory tract (especially the nasal-pharyngeal and tracheo-bronchial regions) and lung (internal dose) is less than that measured at the boundary of the body. A detailed discussion of this concept can be found in *Guidelines for Exposure Assessment* (U.S. EPA, 1992). Suggestions for further reading on the anatomy and physiology of the respiratory system include Phalen et al. (1990), Bates (1989), Cherniack (1972), Forster et al. (1986), and West (2008a, b). When constructing risk assessments that concern the inhalation route of exposure, one must be aware of any adjustments that have been employed in the estimation of the pollutant concentration to account for this reduction in potential dose.

There are also a number of resources available in the literature describing various approaches and techniques related to inhalation rate estimates, including Ridley et al. (2008), Ridley and Olds (2008), Speakman and Selman (2003), Thompson et al. (2009), and Westerterp (2003).

Inclusion of this chapter in the *Exposure Factors Handbook* does not imply that assessors will always need to select and use inhalation rates when evaluating exposure to air contaminants. For example, it is unnecessary to calculate inhaled dose when using dose-response factors from the Integrated Risk Information System (IRIS) (U.S. EPA, 1994), because the IRIS methodology accounts for inhalation rates in the development of "dose-response" relationships. Information in this chapter may be used by toxicologists in their derivation of human equivalent concentrations (HECs), where adjustments are usually required to account for differences in exposure scenarios or populations (U.S. EPA, 1994). Inhalation dosimetry and the factors affecting the disposition of particles and gases that may be deposited or taken up in the respiratory tract are discussed in more detail in the U.S. Environmental Protection Agency's (EPA's) report on *Methods for Derivation of Inhalation Reference Concentrations (RfCs) and Application of Inhalation Dosimetry* (U.S. EPA, 1994). When using IRIS for inhalation risk assessments, "dose-response" relationships require only an average air concentration to evaluate health concerns:

- For non-carcinogens, IRIS uses Reference Concentrations (RfCs), which are expressed in concentration units. Hazard is evaluated by comparing the inspired air concentration to the RfC.
- For carcinogens, IRIS uses unit risk values, which are expressed in inverse concentration units. Risk is evaluated by multiplying the unit risk by the inspired air concentration.

Detailed descriptions of the IRIS methodology for derivation of inhalation RfCs can be found in two methods manuals produced by the Agency (U.S. EPA, 1994, 1992).

The Superfund Program has also updated its approach for determining inhalation risk, eliminating the use of inhalation rates when evaluating exposure to air contaminants (U.S. EPA, 2009b). The current methodology recommends that risk assessors use the concentration of the chemical in air as the exposure metric (e.g., mg/m^3), instead of the intake of a contaminant in air based on inhalation rate and body weight (e.g., mg/kg-day).

Due to their size, physiology, behavior, and activity level, the inhalation rates of children differ from those of adults. Infants and children have a higher resting metabolic rate and oxygen consumption rate per unit of body weight than adults because of their rapid growth and relatively larger lung surface area (SA) per unit of body weight. For example, the oxygen consumption rate for a resting infant between 1 week and 1 year of age is 7 milliliters per kilogram of body weight (mL/kg) per minute, while the rate for an adult under the same conditions is 3−5 mL/kg per minute (WHO, 1986). Thus, while greater amounts of air and pollutants are inhaled by adults than children over similar time periods on an absolute basis, the relative volume of air passing through the lungs of a resting infant is up to twice that of a resting adult on a body-weight basis. It should be noted that lung volume is correlated, among other factors, with a person's height. Also, people living in higher altitudes have larger lung capacity than those living at sea level.

Children's inhalation dosimetry and health effects were topics of discussion at a U.S. Environmental Protection Agency workshop held in June 2006 (Foos and Sonawane, 2008). Age-related differences in lung structure and function, breathing patterns, and how these affect the inhaled dose and the deposition of particles in the lung are important factors in assessing risks from inhalation exposures (Foos et al., 2008). Children more often than adults, breathe through their mouths and, therefore, may have a lesser nasal contribution to breathing during rest and while performing various activities. The uptake of particles in the nasal airways is also less efficient in children (Bennett et al., 2008). Thus, the deposition of particles in the lower respiratory tract may be greater in children (Foos et al., 2008). In addition, the rate of fine particle deposition has been significantly correlated with increased body mass index (BMI), an important point as childhood obesity becomes a greater issue (Bennett and Zeman, 2004).

Recommended inhalation rates (both long- and short-term) for adults and children are provided in Section 6.2, along with the confidence ratings for these recommendations, which are based on four key studies identified by U.S. EPA for this factor. Long-term inhalation is repeated exposure for more than 30 days, up to approximately 10% of the life span in humans (more than 30 days). Long-term inhalation rates for adults and children (including infants) are presented as daily rates (m^3/day). Short-term exposure is repeated exposure for more than 24 hours, up to 30 days. Short-term inhalation rates are reported for adults and children (including infants) performing various activities in m^3/minute. Following the recommendations, the available studies (both key and relevant studies) on inhalation rates are summarized.

6.2. RECOMMENDATIONS

The recommended inhalation rates for adults and children are based on three recent studies (U.S. EPA, 2009a; Stifelman, 2007; Brochu et al., 2006b), as well as an additional study of children (Arcus-Arth and Blaisdell, 2007). These studies represent an improvement upon those previously used for recommended inhalation rates in earlier versions of this handbook, because they use a large data set that is representative of the United States as a whole and consider the correlation between body weight and inhalation rate.

The selection of inhalation rates to be used for exposure assessments depends on the age of the exposed population and the specific activity levels of this population during various exposure scenarios. Table 6-1 presents the recommended long-term values for adults and children (including infants) for use in various exposure scenarios. For children, the age groups included are from U.S. EPA's *Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants* (U.S. EPA, 2005a). Section 6.3.5 describes how key studies were combined to derive the mean and 95th percentile inhalation rate values and the concordance between the age groupings used for adults and children in this chapter and the original age groups in the key studies.

As shown in Table 6-1, the daily average inhalation rates for long-term exposures for children (males and females combined, unadjusted for body weight) range from 3.5 m^3/day for children from 1 to <3 months to 16.3 m^3/day for children aged 16 to <21 years. Mean values for adults range from 12.2 m^3/day (81 years and older) to 16.0 m^3/day (31 to <51 years). The 95th percentile values for children range from 5.8 m^3/day (1 to <3 months) to 24.6 m^3/day (16 to <21 years) and for adults range from 15.7 m^3/day (81 years and older) to 21.4 m^3/day (31 to <41 years). The mean and 95th percentile values shown in Table 6-1 represent averages of the inhalation rate data from the key studies for which data were available for selected age groups.

It should be noted that there may be a high degree of uncertainty associated with the upper percentiles. These values represent unusually high estimates of caloric intake per day and are not representative of the average adult or child. For example, using Layton's equation (Layton, 1993) for estimating metabolically consistent inhalation rates to calculate caloric equivalence (see Section 6.4.9), the 95th percentile value for 16 to <21-year-old children is greater than 4,000 kcal/day (Stifelman, 2003). All of the 95th percentile values listed in Table 6-1 represent unusually high inhalation rates for long-term exposures, even for the upper end of the distribution, but were included in this handbook to provide exposure assessors a sense of the possible range of inhalation rates for adults and children. These values should be used with caution when estimating long-term exposures.

Short-term mean and 95th percentile data in m^3/minute are provided in Table 6-2 for males and females combined for adults and children for whom activity patterns are known. These values represent averages of the activity level data from the one key study from which short-term inhalation rate data were available (U.S. EPA, 2009a).

Table 6-3 shows the confidence ratings for the inhalation rate recommendations. Table 6-4, Table 6-6 through Table 6-8, Table 6-10, Table 6-14, Table 6-15, and Table 6-17 through Table 6-20 provide multiple percentiles for long- and short-term inhalation rates for both males and females.

Table 6-1. Recommended Long-Term Exposure Values for Inhalation (males and females combined)					
Age Group[a]	Mean (m^3/day)	Sources Used for Means	95th Percentile[b] (m^3/day)	Sources Used for 95th Percentiles	Multiple Percentiles
Birth to <1 month	3.6	c	7.1	c	See Table 6-4, Table 6-6 through Table 6-8, Table 6-10, Table 6-14 Table 6-15 [none available for Stifelman (2007)]
1 to <3 months	3.5	c, d	5.8	c, d	
3 to <6 months	4.1	c, d	6.1	c, d	
6 to <12 months	5.4	c, d	8.0	c, d	
Birth to <1 year	5.4	c, d, e, f	9.2	c, d, e	
1 to <2 years	8.0	c, d, e, f	12.8	c, d, e	
2 to <3 years	8.9	c, d, e, f	13.7	c, d, e	
3 to <6 years	10.1	c, d, e, f	13.8	c, d, e	
6 to <11 years	12.0	c, d, e, f	16.6	c, d, e	
11 to <16 years	15.2	c, d, e, f	21.9	c, d, e	
16 to <21 years	16.3	c, d, e, f	24.6	c, d, e	
21 to <31 years	15.7	d, e, f	21.3	d, e	
31 to <41 years	16.0	d, e, f	21.4	d, e	
41 to <51 years	16.0	d, e, f	21.2	d, e	
51 to <61 years	15.7	d, e, f	21.3	d, e	
61 to <71 years	14.2	d, e, f	18.1	d, e	
71 to <81 years	12.9	d, e	16.6	d, e	
≥81 years	12.2	d, e	15.7	d, e	

a When age groupings in the original reference did not match the U.S. EPA groupings used for this handbook, means from all age groupings in the original reference that overlapped U.S. EPA's age groupings by more than one year were averaged, weighted by the number of observations contributed from each age group. Similar calculations were performed for the 95th percentiles. See Table 6-25 for concordance with U.S. EPA age groupings.

b Some 95th percentile values may be unrealistically high and not representative of the average person.

c Arcus-Arth and Blaisdell (2007).

d Brochu et al. (2006b).

e U.S. EPA (2009a).

f Stifelman (2007).

Table 6-2. Recommended Short-Term Exposure Values for Inhalation (males and females combined)

Activity Level	Age Group (years)	Mean (m^3/minute)	95[th] Percentile (m^3/minute)	Multiple Percentiles
Sleep or Nap	Birth to <1	3.0E−03	4.6E−03	See Table 6-17 and Table 6-19
	1 to <2	4.5E−03	6.4E−03	
	2 to <3	4.6E−03	6.4E−03	
	3 to <6	4.3E−03	5.8E−03	
	6 to <11	4.5E−03	6.3E−03	
	11 to <16	5.0E−03	7.4E−03	
	16 to <21	4.9E−03	7.1E−03	
	21 to <31	4.3E−03	6.5E−03	
	31 to <41	4.6E−03	6.6E−03	
	41 to <51	5.0E−03	7.1E−03	
	51 to <61	5.2E−03	7.5E−03	
	61 to <71	5.2E−03	7.2E−03	
	71 to <81	5.3E−03	7.2E−03	
	≥81	5.2E−03	7.0E−03	
Sedentary/ Passive	Birth to <1	3.1E−03	4.7E−03	
	1 to <2	4.7E−03	6.5E−03	
	2 to <3	4.8E−03	6.5E−03	
	3 to <6	4.5E−03	5.8E−03	
	6 to <11	4.8E−03	6.4E−03	
	11 to <16	5.4E−03	7.5E−03	
	16 to <21	5.3E−03	7.2E−03	
	21 to <31	4.2E−03	6.5E−03	
	31 to <41	4.3E−03	6.6E−03	
	41 to <51	4.8E−03	7.0E−03	
	51 to <61	5.0E−03	7.3E−03	
	61 to <71	4.9E−03	7.3E−03	
	71 to <81	5.0E−03	7.2E−03	
	≥81	4.9E−03	7.0E−03	
Light Intensity	Birth to <1	7.6E−03	1.1E−02	
	1 to <2	1.2E−02	1.6E−02	
	2 to <3	1.2E−02	1.6E−02	
	3 to <6	1.1E−02	1.4E−02	
	6 to <11	1.1E−02	1.5E−02	
	11 to <16	1.3E−02	1.7E−02	
	16 to <21	1.2E−02	1.6E−02	

Table 6-2. Recommended Short-Term Exposure Values for Inhalation (males and females combined) (continued)				
Activity Level	Age Group (year)	Mean (m^3/minute)	95th Percentile (m^3/minute)	Multiple Percentiles
Light Intensity (continued)	21 to <31	1.2E−02	1.6E−02	
	31 to <41	1.2E−02	1.6E−02	
	41 to <51	1.3E−02	1.6E−02	
	51 to <61	1.3E−02	1.7E−02	
	61 to <71	1.2E−02	1.6E−02	
	71 to <81	1.2E−02	1.5E−02	
	≥81	1.2E−02	1.5E−02	
Moderate Intensity	Birth to <1	1.4E−02	2.2E−02	
	1 to <2	2.1E−02	2.9E−02	
	2 to <3	2.1E−02	2.9E−02	
	3 to <6	2.1E−02	2.7E−02	
	6 to <11	2.2E−02	2.9E−02	
	11 to <16	2.5E−02	3.4E−02	
	16 to <21	2.6E−02	3.7E−02	
	21 to <31	2.6E−02	3.8E−02	
	31 to <41	2.7E−02	3.7E−02	
	41 to <51	2.8E−02	3.9E−02	
	51 to <61	2.9E−02	4.0E−02	
	61 to <71	2.6E−02	3.4E−02	
	71 to <81	2.5E−02	3.2E−02	
	≥81	2.5E−02	3.1E−02	
High Intensity	Birth to <1	2.6E−02	4.1E−02	
	1 to <2	3.8E−02	5.2E−02	
	2 to <3	3.9E−02	5.3E−02	
	3 to <6	3.7E−02	4.8E−02	
	6 to <11	4.2E−02	5.9E−02	
	11 to <16	4.9E−02	7.0E−02	
	16 to <21	4.9E−02	7.3E−02	
	21 to <31	5.0E−02	7.6E−02	
	31 to <41	4.9E−02	7.2E−02	
	41 to <51	5.2E−02	7.6E−02	
	51 to <61	5.3E−02	7.8E−02	
	61 to <71	4.7E−02	6.6E−02	
	71 to <81	4.7E−02	6.5E−02	
	≥81	4.8E−02	6.8E−02	

Source: U.S. EPA (2009a).

Table 6-3. Confidence in Recommendations for Long- and Short-Term Inhalation Rates

General Assessment Factors	Rationale	Rating
Soundness		Medium
Adequacy of Approach	The survey methodology and data analysis was adequate. Measurements were made by indirect methods. The studies analyzed existing primary data.	
Minimal (or defined) Bias	Potential bias within the studies was fairly well documented.	
Applicability and Utility		High
Exposure Factor of Interest	The studies focused on inhalation rates and factors influencing them.	
Representativeness	The studies focused on the U.S. population. A wide range of age groups were included.	
Currency	The studies were published during 2006 and 2009 and represent current exposure conditions.	
Data-Collection Period	The data-collection period for the studies may not be representative of long-term exposures.	
Clarity and Completeness		Medium
Accessibility	All key studies are available from the peer-reviewed literature.	
Reproducibility	The methodologies were clearly presented; enough information was included to reproduce most results.	
Quality Assurance	Information on ensuring data quality in the key studies was limited.	
Variability and Uncertainty		Medium
Variability in Population	In general, the key studies addressed variability in inhalation rates based on age and activity level. Although some factors affecting inhalation rate, such as body mass, are discussed, other factors (e.g., ethnicity) are omitted.	
Uncertainty	Multiple sources of uncertainty exist for these studies. Assumptions associated with energy expenditure (EE)-based estimation procedures are a source of uncertainty in inhalation rate estimates.	
Evaluation and Review		High
Peer Review	Three of the key studies appeared in peer-reviewed journals, and one key study is a U.S. EPA peer-reviewed report.	
Number and Agreement of Studies	There are four key studies. The results of studies from different researchers are in general agreement.	
Overall Rating		**Medium**

6.3. KEY INHALATION RATE STUDIES

6.3.1. Brochu et al. (2006b)—Physiological Daily Inhalation Rates for Free-Living Individuals Aged 1 Month to 96 Years, Using Data From Doubly Labeled Water Measurements: A Proposal for Air Quality Criteria, Standard Calculations, and Health Risk Assessment

Brochu et al. (2006b) calculated physiological daily inhalation rates (PDIRs) for 2,210 individuals aged 3 weeks to 96 years using the reported disappearance rates of oral doses of doubly labeled water (DLW) (^2H_2O and $H_2{}^{18}O$) in urine, monitored by gas-isotope-ratio mass spectrometry for an aggregate period of more than 30,000 days. DLW data were complemented with indirect calorimetry and nutritional balance measurements.

In the DLW method, the disappearance of the stable isotopes deuterium (^2H) and heavy oxygen-18 (^{18}O) are monitored in urine, saliva, or blood samples over a long period of time (from 7 to 21 days) after subjects receive oral doses of ^2H_2O and $H_2{}^{18}O$. The disappearance rate of ^2H reflects water output and that of ^{18}O represents water output plus carbon dioxide (CO_2) production rates. The CO_2 production rate is then calculated by finding the difference between the two disappearance rates. Total daily energy expenditures (TDEEs) are determined from CO_2 production rates using classic respirometry formulas, in which values for the respiratory quotient ($RQ = CO_{2\ produced}/O_{2\ consumed}$) are derived from the composition of the diet during the period of time of each study. The DLW method also allows for measurement of the energy cost of growth (ECG). TDEE and ECG measurements can be converted into PDIR values using the following equation developed by Layton (1993):

$$PDIR = (TDEE + ECG) \times H \times VQ \times 10^{-3} \quad \text{(Eqn. 6-1)}$$

where:

PDIR	=	physiological daily inhalation rates (m^3/day);
TDEE	=	total daily energy expenditure (kcal/day);
ECG	=	stored daily energy cost for growth (kcal/day);
H	=	oxygen uptake factor, volume of 0.21 L of oxygen (at standard temperature and pressure, dry air) consumed to produce 1 kcal of energy expended;
VQ	=	ventilatory equivalent (ratio of the minute volume [V_E] at body temperature pressure saturation to the oxygen uptake rate [VO_2] at standard temperature and pressure, dry air) $V_E/VO_2 = 27$; and
10^{-3}	=	conversion factor (L/m^3).

Brochu et al. (2006b) calculated daily inhalation rates (DIRs) (expressed in m^3/day and m^3/kg-day) for the following age groups and physiological conditions: (1) healthy newborns aged 3 to 5 weeks old (N = 33), (2) healthy normal-weight males and females aged 2.6 months to 96 years (N = 1,252), (3) low-BMI subjects (underweight women, N = 17; adults from less affluent societies N = 59) and (4) overweight/obese individuals (N = 679), as well as (5) athletes, explorers, and soldiers when reaching very high energy expenditures (N = 170). Published data on BMI, body weight, basal metabolic rate (BMR), ECG, and TDEE measurements (based on DLW method and indirect calorimetry) for subjects aged 2.6 months to 96 years were used. Data for underweight, healthy normal-weight, and overweight/obese individuals were gathered and defined according to BMI cutoffs. Data for newborns were included regardless of BMI values because they were clinically evaluated as being healthy infants.

Table 6-4 to Table 6-8 present the distribution of daily inhalation rates for normal-weight and overweight/obese individuals by sex and age groups. Table 6-9 presents mean inhalation rates for newborns. Due to the insufficient number of subjects, no distributions were derived for this group.

An advantage of this study is that data are provided for age groups of less than 1 year. A limitation of this study is that data for individuals with pre-existing medical conditions were lacking.

6.3.2. Arcus-Arth and Blaisdell (2007)—Statistical Distributions of Daily Breathing Rates for Narrow Age Groups of Infants and Children

Arcus-Arth and Blaisdell (2007) derived daily breathing rates for narrow age ranges of children using the metabolic conversion method of Layton (1993) and energy intake (EI) data adjusted to represent the U.S. population from the Continuing Survey of Food Intake for Individuals (CSFII) 1994−1996, 1998. Normalized (m^3/kg-day) and non-normalized (m^3/day) breathing rates for children 0−18 years of age were derived using the general equation developed by Layton (1993) to calculate energy-dependent inhalation rates:

$$V_E = H \times VQ \times EE \qquad \text{(Eqn. 6-2)}$$

where:

V_E = volume of air breathed per day (m^3/day),
H = volume of oxygen consumed to produce 1 kcal of energy (m^3/kcal),
VQ = ratio of the volume of air to the volume of oxygen breathed per unit time (unitless), and
EE = energy (kcal) expended per day.

Arcus-Arth and Blaisdell (2007) calculated *H* values of 0.22 and 0.21 for infants and non-infant children, respectively, using the 1977−1978 Nationwide Food Consumption Survey (NFCS) and CSFII data sets. Ventilatory equivalent (VQ) data, including those for infants, were obtained from 13 studies that reported VQ data for children aged 4−8 years. Separate preadolescent (4−8 years) and adolescent (9−18 years) VQ values were calculated in addition to separate VQ values for adolescent boys and girls. Two-day-averaged daily EI values reported in the CSFII data set were used as a surrogate for EE. CSFII records that did not report body weight and those for children who consumed breast milk or were breast-fed were excluded from their analyses. The EIs of children 9 years of age and older were multiplied by 1.2, the value calculated by Layton (1993) to adjust for potential bias related to under-reporting of dietary intakes by older children. For infants, EI values were adjusted by subtracting the amount of energy put into storage by infants as estimated by Scrimshaw et al. (1996). Self-reported body weights for each individual from the CSFII data set were used to calculate non-normalized (m^3/day) and normalized (m^3/kg-day) breathing rates, which decreased the variability in the resulting breathing rate data. Daily breathing rates were grouped into three 1-month groups for infants, 1-year age groups for children 1 to 18 years of age, and the age groups recommended by U.S. EPA *Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens* (U.S. EPA, 2005b) to receive greater weighting for mutagenic carcinogens (0 to <2 years of age, and 2 to <16 years of age). Data were also presented for adolescent boys and girls, aged 9 to 18 years (see Table 6-10). For each age and age-sex group, Arcus-Arth and Blaisdell (2007) calculated the arithmetic mean, standard error of the mean, percentiles (50th, 90th, and 95th), geometric mean, standard deviation, and best-fit parametric models of the breathing rate distributions. Overall, the CSFII-derived non-normalized breathing rates progressively increased with age from infancy through 18 years of age, while normalized breathing rates progressively decreased. The data are presented in Table 6-11 in units of m^3/day. There were statistical differences between boys and girls 9 to 18 years of age, both for these years combined ($p < 0.00$) and for each year of age separately ($p < 0.05$). The authors reasoned that since the fat-free mass (basically muscle mass) of boys typically increases during adolescence, and because fat-free mass is highly correlated to basal metabolism which accounts for the majority of EE, non-normalized breathing rates for adolescent boys may be expected to increase with increasing age. Table 6-11 presents the mean and 95th percentile values for males and females combined, averaged to fit within the standard U.S. EPA age groups.

The CSFII-derived mean breathing rates derived by Arcus-Arth and Blaisdell (2007) were compared to the mean breathing rates estimated in studies that utilized DLW technique EE data that had been coupled with the Layton (1993) method. Infants' breathing rates estimated using the CSFII data were 15 to 27% greater than the comparison DLW EE breathing rates. In contrast, the children's CSFII breathing rates ranged from 23% less to 14% greater than comparison rates. Arcus-Arth and Blaisdell (2007) concluded that taking into account the differences in methods, data, and some age definitions between the two sets of breathing rates, the CSFII and comparison rates were similar across age groups.

An advantage of this study is that it provides breathing rates specific to narrow age ranges, which can be useful for assessing inhalation dose during periods of greatest susceptibility. However, the study is limited by the potential for misreporting, underestimating, or overestimating of food intake data in the CSFII. In addition to underreporting of food intake by adolescents, EI values for younger children may be under- or overestimated. Overweight children (or their parents) may also under-report food intakes. In addition, adolescents who misreport food intake may have also misreported body weights.

6.3.3. Stifelman (2007)—Using Doubly Labeled Water Measurements of Human Energy Expenditure to Estimate Inhalation Rates

Stifelman (2007) estimated inhalation rates using DLW energy data. The DLW method administers two forms of stable isotopically labeled water: deuterium-labeled (^2H_2O) and ^{18}oxygen-labeled ($H_2{}^{18}O$). The difference in disappearance rates between the two isotopes represents the energy expended over a period of 1−3 half-lives of the labeled water (Stifelman, 2007). The resulting duration of observation is typically 1−3 weeks, depending on the size and activity level.

The DLW database contains subjects from areas around the world and represents diversity in ethnicity, age, activity, body type, and fitness level. DLW data have been compiled by the Institute of Medicine (IOM) Panel on Macronutrients and the Food and Agriculture Organization of the United Nations. Stifelman (2007) used the equation of Layton (1993) to convert the recommended energy levels of IOM for the active to very-active people to their equivalent inhalation rates. The IOM reports recommend energy expenditure levels organized by sex, age, and body size (Stifelman, 2007).

The equivalent inhalation rates are shown in Table 6-12. Shown in Table 6-13 are the mean values for the IOM "active" energy level category, averaged to fit within the standard U.S. EPA age groups. Stifelman (2007) noted that the estimates based on the DLW are consistent with previous findings of Layton (1993) and the *Exposure Factors Handbook* (U.S. EPA, 1997) and that inhalation rates based on the IOM active classification are consistent with the mean inhalation rate in the handbook.

The advantages of this study are that the inhalation rates were estimated using the DLW data from a large data set. Stifelman (2007) noted that DLW methods are advantageous; the data are robust, measurements are direct and avoid errors associated with indirect measurements (heart rate [HR]), subjects are free-living, and the period of observation is longer than what is possible from staged activity measures. Observations over a longer period of time reduce the uncertainties associated with using short duration studies to infer long-term inhalation rates. A limitation with the study is that the inhalation rates that are presented are for active/very active persons only.

6.3.4. U.S. EPA (2009a)—Metabolically Derived Human Ventilation Rates: A Revised Approach Based Upon Oxygen Consumption Rates

U.S. EPA (2009a) conducted a study to ascertain inhalation rates for children and adults. Specifically, U.S. EPA sought to improve upon the methodology used by Layton (1993) and other studies that relied upon the VQ and a linear relationship between oxygen consumption and fitness rate. A revised approach, developed by U.S. EPA's National Exposure Research Laboratory, was used, in which an individual's inhalation rate was derived from his or her assumed oxygen consumption rate. U.S. EPA applied this revised approach using body-weight data from the 1999−2002 National Health and Nutrition Examination Survey (NHANES) and metabolic equivalents of work (METS) data from U.S. EPA's Consolidated Human Activity Database (CHAD). In this database, metabolic cost is given in units of "METS" or "metabolic equivalents of work," an energy expenditure metric used by exercise physiologists and clinical nutritionists to represent activity levels. An activity's METS value represents a dimensionless ratio of its metabolic rate (energy expenditure) to a person's resting, or BMR.

NHANES provided age, sex, and body-weight data for 19,022 individuals from throughout the United States. From these data, BMR was estimated using an age-specific linear equation used in the *Exposure Factors Handbook* (U.S. EPA, 1997), and in several other studies and reference works.

The CHAD database is a compilation of several databases of human activity patterns. U.S. EPA used one of these studies, the National Human Activity Pattern Survey (NHAPS), as its source for METS values because it was more representative of the entire U.S. population than the other studies in the database. The NHAPS data set included activity data for 9,196 individuals, each of which provided 24 hours of activity pattern data using a diary-based questionnaire. While NHAPS was identified as the best available data source for activity patterns, there were some shortcomings in the quality of the data. Study respondents did not provide body weights; instead, body weights were simulated using statistical sampling. Also, the NHAPS data extracted from CHAD could not be corrected to account for non-random sampling of study participants and survey days.

NHANES and NHAPS data were grouped according to the age categories presented elsewhere in this handbook, with the exception that children under the age of 1 year were placed into a single category to preserve an adequate sample size within the category. For each NHANES participant, a "simulated" 24-hour activity pattern was generated by randomly sampling activity patterns from the set of NHAPS participants with the same sex and age category as the NHANES participant. Twenty such patterns were selected at random for each NHANES participant, resulting in 480 hours of simulated activity data for each NHANES participant. The data were then scaled down to a 24-hour time frame to yield an average 24-hour activity pattern for each of the 19,022 NHANES individuals.

Each activity was assigned a METS value based on statistical sampling of the distribution assigned by CHAD to each activity code. For most codes, these distributions were not age dependent, but age was a factor for some activities for which intensity level varies strongly with age. Using statistical software, equations for METS based on normal, lognormal, exponential, triangular, and uniform distributions were generated as needed for the various activity codes. The METS values were then translated into EE by multiplying the METS by the BMR, which was calculated as a linear function of body weight. The oxygen consumption rate (VO_2) was calculated by multiplying EE by *H*, the volume of oxygen consumed per unit of energy. VO_2 was calculated both as volume per time and as volume per time per unit of body weight.

The inhalation rate for each activity within the 24-hour simulated activity pattern for each individual was estimated as a function of VO_2, body weight, age, and sex. Following this, the average inhalation rate was calculated for each individual for the entire 24-hour period, as well as for four separate classes of activities based on METS value (sedentary/passive [METS less than or equal to 1.5], light intensity [METS greater than 1.5 and less than or equal to 3.0], moderate intensity [METS greater than 3.0 and less than or equal to 6.0], and high intensity [METS greater than 6.0]). Data for individuals were then used to generate summary tables based on sex and age categories.

U.S. EPA (2009a) also conducted a validation exercise using the Air Pollutants Exposure Model to estimate ventilation rates (VRs) and compared results with recently published estimates of ventilation rates from Brochu et al. (2006b; 2006a) and Arcus-Arth and Blaisdell (2007). The results compared reasonably well when ventilation rates were normalized by BMI.

Table 6-14 through Table 6-22 present data from this study. Table 6-14 and Table 6-15 present, for male and female subjects, respectively, summary statistics for daily average inhalation rate by age category on a volumetric (m^3/day) and body-weight adjusted (m^3/day-kg) basis. Table 6-16 presents the mean and 95th percentile values for males, females, and males and females combined. Table 6-17 through Table 6-20 present, for male and female subjects, respectively, mean ventilation rates by age category on a volumetric (m^3/minute) and body-weight adjusted (m^3/minute-kg) basis for the five different activity level ranges described above. Table 6-21 and Table 6-22 present the number of hours spent per day at each activity level by males and females.

An advantage of this study is the large sample size. In addition, the data sets used, NHAPS and NHANES, are representative of the U.S. general population. One limitation is that the NHAPS data are more than 15 years old. Also, day-to-day variability cannot be characterized because data were collected over a 24-hour period. There is also uncertainty in the METs randomization, all of which were noted by the authors. In addition, the approach does not take into consideration correlations that may exist between body weight and activity patterns. Therefore, high physical activity levels can be associated with individuals of high body weight, leading to unrealistically high inhalation rates at the upper percentile levels. The validation exercise presented in U.S. EPA (2009a) used normal-weight individuals. It is unclear if similar results would be obtained for overweight individuals.

6.3.5. Key Studies Combined

In order to provide the recommended long-term inhalation rates shown in Table 6-1, data from the four key studies were combined. Mean and 95th percentile inhalation rate values for the four key studies are shown in Table 6-23 and Table 6-24, respectively. The data from each study were averaged by sex and grouped according to the age groups selected for use in this handbook, when possible. Table 6-25 shows concordance between the age groupings used in this handbook and the original age groups in the key studies.

6.4. RELEVANT INHALATION RATE STUDIES

6.4.1. International Commission on Radiological Protection (ICRP) (1981)—Report of the Task Group on Reference Man

The International Commission on Radiological Protection (ICRP, 1981) estimated daily inhalation rates for reference adult males and females, children (10 years old), infants (1 year old), and newborn babies by using a time-activity-ventilation approach. This approach for estimating an inhalation rate over a specified period of time was based on calculating a time weighted average of inhalation rates associated with physical activities of varying durations (see Table 6-26). ICRP (1981) compiled reference values (see Table 6-27) of minute volume/inhalation rates from various literature sources. ICRP (1981) assumed that the daily activities of a reference male, female, and child (10 years of age) consisted of 8 hours of rest and 16 hours of light activities. It was also assumed that for adults only, the 16 hours of light activities were divided evenly between occupational and non-occupational activities. It was assumed that a day consisted of 14 hours resting and 10 hours light activity for an infant (1 year). A newborn's daily activities consisted of 23 hours resting and 1-hour light activity. The estimated inhalation rates were 22.8 m^3/day for adult males, 21.1 m^3/day for adult females, 14.8 m^3/day for children (age 10 years), 3.76 m^3/day for infants (age 1 year), and 0.78 m^3/day for newborns (see Table 6-26).

The advantages of this study are that they account fairly well for time and activity, and are sex specific. A limitation associated with this study is that it is almost 30 years old. In addition, the validity and accuracy of the inhalation rate data used in the compilation of reference values were not specified. This introduces some degree of uncertainty in the results obtained. Also, the approach used required that assumptions be made regarding the hours spent by various age/sex cohorts in specific activities. These assumptions may over-/under-estimate the inhalation rates obtained.

6.4.2. U.S. EPA (1985)—Development of Statistical Distributions or Ranges of Standard Factors Used in Exposure Assessment

The U.S. EPA (1985) compiled measured values of minute ventilation for various age/sex cohorts from early studies. The data compiled by the U.S. EPA (1985) for each of the age/sex cohorts were obtained at various activity levels (see Table 6-28). These levels were categorized as light, moderate, or heavy according to the criteria developed by the U.S. EPA Office of Environmental Criteria and Assessment for the Ozone Criteria Document. These criteria were developed for a reference male adult with a body weight of 70 kg (U.S. EPA, 1985). Table 6-29 details the estimated minute ventilation rates for adult males based on these activity level categories.

Table 6-28 presents a summary of inhalation rates by age and activity level. A description of activities included in each activity level is also presented in Table 6-28. Table 6-28 indicates that at rest, the average adult inhalation rate is 0.5 m^3/hour. Table 6-28 indicates that at rest, the mean inhalation rate for children, ages 6 and 10 years, is 0.4 m^3/hour. Table 6-30 presents activity pattern data aggregated for three microenvironments by activity level for all age groups. The total average hours spent indoors was 20.4, outdoors was 1.77, and in a transportation vehicle was 1.77. Based on the data presented in Table 6-28 and Table 6-30, a daily inhalation rate was calculated for adults and children by using a time-activity-ventilation approach. These data are presented for adults and children in Table 6-31. The calculated average daily inhalation rate is 16 m^3/day for adults. The average daily inhalation rate for 6- and 10-year-old children is 16.74 and 21.02 m^3/day, respectively.

Limitations associated with this study are its age and that many of the values used in the data compilation were from early studies. The accuracy and/or validity of the values used and data collection method were not presented in U.S. EPA (1985). This introduces uncertainty in the results obtained. An advantage of this study is that the data are actual measurement data for a large number of adults and children.

6.4.3. Shamoo et al. (1990)—Improved Quantitation of Air Pollution Dose Rates by Improved Estimation of Ventilation Rate

Shamoo et al. (1990) conducted a study to develop and validate new methods to accurately estimate ventilation rates for typical individuals during their normal activities. Two practical approaches were tested for estimating ventilation rates indirectly: (1) volunteers were trained to estimate their own VR at various controlled levels of exercise; and (2) individual VR and HR relationships were determined in another set of volunteers during supervised exercise sessions (Shamoo et al., 1990). In the first approach, the training session involved 9 volunteers (3 females and 6 males) from 21 to 37 years old. Initially the subjects were trained on a treadmill with regularly increasing speeds. VR measurements were recorded during the last minute of the 3-minute interval at each speed. VR was reported to the subjects as low (1.4 m^3/hour), medium (1.5−2.3 m^3/hour), heavy (2.4−3.8 m^3/hour), and very heavy (3.8 m^3/hour or higher) (Shamoo et al., 1990).

Following the initial test, treadmill training sessions were conducted on a different day in which 7 different speeds were presented, each for 3 minutes in arbitrary order. VR was measured, and the subjects were given feedback with the four ventilation ranges provided previously. After resting, a treadmill testing session was conducted in which seven speeds were presented in different arbitrary order from the training session. VR was measured, and each subject estimated their own ventilation level at each speed. The correct level was then revealed to each subject after his/her own estimate. Subsequently, two 3-hour outdoor supervised exercise sessions were conducted in the summer on 2 consecutive days. Each hour consisted of 15 minutes each of rest, slow walking, jogging, and fast walking. The subjects' ventilation level and VR were recorded; however, no feedback was given to the subjects. Electrocardiograms were recorded via direct connection or telemetry, and HR was measured concurrently with ventilation measurement for all treadmill sessions.

The second approach consisted of two protocol phases (indoor/outdoor exercise sessions and field testing). Twenty outdoor adult workers between 19 and 50 years old were recruited. Indoor and outdoor supervised exercises similar to the protocols in the first approach were conducted; however, there were no feedbacks. Also, in this approach, electrocardiograms were recorded, and HR was measured concurrently with VR. During the field testing phase, subjects were trained to record their activities during three different 24-hour periods during 1 week. These periods included their most active working and non-working days. HR was measured quasi-continuously during the 24-hour periods that activities were recorded. The subjects recorded in a diary all changes in physical activity, location, and exercise levels during waking hours. Self-estimated activities in supervised exercises and field studies were categorized as slow (resting, slow walking or equivalent), medium (fast walking or equivalent), and fast (jogging or equivalent).

Inhalation rates were not presented in this study. In the first approach, about 68% of all self-estimates were correct for the 9 subjects sampled (Shamoo et al., 1990). Inaccurate self-estimates occurred in the younger male population who were highly physically fit and were competitive aerobic trainers. This subset of the sample population tended to underestimate their own physical activity levels at higher VR ranges. Shamoo et al. (1990) attributed this to a "macho effect," in which these younger male subjects were reluctant to report "very heavy" exercise even when it was obvious to an observer, because they considered it an admission of poor physical condition. In the second approach, a regression analysis was conducted that related the logarithm of VR to HR. The logarithm of VR correlated better with HR than VR itself (Shamoo et al., 1990).

Limitations associated with this study are its age and that the population sampled is not representative of the general U.S. population. Also, ventilation rates were not presented. Training individuals to estimate their VR may contribute to uncertainty in the results because the estimates are subjective. Another limitation is that calibration data were not obtained at extreme conditions; therefore, the VR/HR relationship obtained may be biased. An additional limitation is that training subjects may be too labor-intensive for widespread use in exposure assessment studies. An advantage of this study is that HR recordings are useful in predicting ventilation rates, which, in turn, are useful in estimating exposure.

6.4.4. Shamoo et al. (1991)—Activity Patterns in a Panel of Outdoor Workers Exposed to Oxidant Pollution

Shamoo et al. (1991) investigated summer activity patterns in 20 adult volunteers with potentially high exposure to ambient oxidant pollution. The selected volunteer subjects were 15 men and 5 women ages 19−50 years from the Los Angeles area. All volunteers worked outdoors at least 10 hours per week. The experimental approach involved two stages: (1) indirect objective estimation of VR from HR measurements, and (2) self-estimation of inhalation/ventilation rates recorded by subjects in diaries during their normal activities.

The approach consisted of calibrating the relationship between VR and HR for each test subject in controlled exercise; monitoring by subjects of their own normal activities with diaries and electronic HR recorders; and then relating VR with the activities described in the diaries (Shamoo et al., 1991). Calibration tests were conducted for indoor and outdoor supervised exercises to determine individual relationships between VR and HR. Indoors, each subject was tested on a treadmill at rest and at increasing speeds. HR and VR were measured at the third minute at each 3-minute interval speed. In addition, subjects were tested while walking a 90-meter course in a corridor at 3 self-selected speeds (normal, slower than normal, and faster than normal) for 3 minutes.

Two outdoor testing sessions (1 hour each) were conducted for each subject, 7 days apart. Subjects exercised on a 260-meter asphalt course. A session involved 15 minutes each of rest, slow walking, jogging, and fast walking during the first hour. The sequence was also repeated during the second hour. HR and VR measurements were recorded starting at the 8th minute of each 15-minute segment. Following the calibration tests, a field study was conducted in which subjects self-monitored their activities by filling out activity diary booklets, self-estimated their breathing rates, and their HR. Breathing rates were defined as sleep; slow (slow or normal walking); medium (fast walking); and fast (running) (Shamoo et al., 1991). Changes in location, activity, or breathing rates during three 24-hour periods within a week were recorded. These periods included their most active working and non-working days. Each subject wore Heart Watches, which recorded their HR once per minute during the field study. Ventilation rates were estimated for the following categories: sleep, slow, medium, and fast.

Calibration data were fit to the equation log (VR) = intercept + (slope × HR), each individual's intercept and slope were determined separately to provide a specific equation that predicts each subject's VR from measured HR (Shamoo et al., 1991). The average measured VRs were 0.48, 0.90, 1.68, and 4.02 m^3/hour for rest, slow walking or normal walking, fast walking, and jogging, respectively (Shamoo et al., 1991). Collectively, the diary recordings showed that sleep occupied about 33% of the subject's time; slow activity 59%; medium activity 7%; and fast activity 1%. The diary data covered an average of 69 hours per subject (Shamoo et al., 1991). Table 6-32 presents the distribution pattern of predicted ventilation rates and equivalent ventilation rates (EVR) obtained at the four activity levels. EVR was defined as the VR per square meter of body surface area, and also as a percentage of the subjects average VR over the entire field monitoring period (Shamoo et al., 1991). The overall mean predicted VR was 0.42 m^3/hour for sleep; 0.71 m^3/hour for slow activity; 0.84 m^3/hour for medium activity; and 2.63 m^3/hour for fast activity.

Table 6-33 presents the mean predicted VR and standard deviation, and the percentage of time spent in each combination of VR, activity type (essential and non-essential), and location (indoor and outdoor). Essential activities include income-related work, household chores, child care, study and other school activities, personal care, and destination-oriented travel. Non-essential activities include sports and active leisure, passive leisure, some travel, and social or civic activities (Shamoo et al., 1991). Table 6-33 shows that inhalation rates were higher outdoors than indoors at slow, medium, and fast activity levels. Also, inhalation rates were higher for outdoor non-essential activities than for indoor non-essential activity levels at slow, medium, and fast self-reported breathing rates (see Table 6-33).

An advantage of this study is that subjective activity diary data can provide exposure modelers with useful rough estimates of VR for groups of generally healthy people. A limitation of this study is its age and that the results obtained show high within-person and between-person variability in VR at each diary-recorded level, indicating that VR estimates from diary reports could potentially be substantially misleading in individual cases. Another limitation of this study is that elevated HR data of slow activity at the second hour of the exercise session reflect persistent effects of exercise and/or heat stress. Therefore, predictions of VR from the VR/HR relationship may be biased.

6.4.5. Linn et al. (1992)—Documentation of Activity Patterns in "High-Risk" Groups Exposed to Ozone in the Los Angeles Area

Linn et al. (1992) conducted a study that estimated the inhalation rates for "high-risk" population groups exposed to ozone in their daily activities in the Los Angeles area. The population surveyed consisted of seven subject panels: Panel 1: 20 healthy outdoor workers (15 males, 5 females, ages 19−50 years); Panel 2: 17 healthy elementary school students (5 males, 12 females, ages 10−12 years); Panel 3: 19 healthy high school students (7 males, 12 females, ages 13−17 years); Panel 4: 49 asthmatic adults (clinically mild, moderate, and severe, 15 males, 34 females, ages 18−50 years); Panel 5: 24 asthmatic adults from 2 neighborhoods of contrasting O_3 air quality (10 males, 14 females, ages 19−46 years); Panel 6: 13 young asthmatics (7 males, 6 females, ages 11−16 years); and Panel 7: construction workers (7 males, ages 26−34 years). An initial calibration test was conducted, followed by a training session. Finally, a field study that involved the subjects collecting their own HRs and diary data was conducted. During the calibration tests, VR, breathing rate, and HR were measured simultaneously at each exercise level. From the calibration data, an equation was developed using linear regression analysis to predict VR from measured HR.

In the field study, each subject (except construction workers) recorded in diaries their daily activities, change in locations (indoors, outdoors, or in a vehicle), self-estimated breathing rates during each activity/location, and time spent at each activity/location. Healthy subjects recorded their HR once every 60 seconds using a Heart Watch, an automated system consisting of a transmitter and receiver worn on the body. Asthmatic subjects recorded their diary information once every hour. Subjective breathing rates were defined as slow (walking at their normal pace), medium (faster than normal walking), and fast (running or similarly strenuous exercise). Table 6-34 presents the calibration and field protocols for self-monitoring of activities for each subject panel.

Table 6-35 presents the mean, 99th percentile, and mean VR at each subjective activity level (slow, medium, fast). The mean and 99th percentile VR were derived from all HR recordings that appeared to be valid, without considering the diary data. Each of the three activity levels was determined from both the concurrent diary data and HR recordings by direct calculation or regression. The mean VR for healthy adults was 0.78 m^3/hour, while the mean VR for asthmatic adults was 1.02 m^3/hour (see Table 6-35). The preliminary data for construction workers indicated that during a 10-hour work shift, their mean VR (1.50 m^3/hour) exceeded the VRs of all other subject panels (see Table 6-35). The authors reported that the diary data showed that on a typical day, most individuals spent most of their time indoors at slow activity level. During slow activity, asthmatic subjects had higher VRs than healthy subjects (see Table 6-35). The authors also reported that in every panel, the predicted VR correlated significantly with the subjective estimates of activity levels.

A limitation of this study is that calibration data may overestimate the predictive power of HR during actual field monitoring. The wide variety of exercises in everyday activities may result in greater variation of the VR-HR relationship than was calibrated. Another limitation is the small sample size of each population surveyed. An advantage of this study is that diary data can provide rough estimates of ventilation patterns, which are useful in exposure assessments. Another advantage is that inhalation rates were presented for various populations (i.e., healthy outdoor adult workers, healthy children, asthmatics, and construction workers).

6.4.6. Shamoo et al. (1992)—Effectiveness of Training Subjects to Estimate Their Level of Ventilation

Shamoo et al. (1992) conducted a study where nine non-sedentary subjects in good health were trained on a treadmill to estimate their own ventilation rates at four activity levels: low, medium, heavy, and very heavy. The purpose of the study was to train the subjects' self-estimation of ventilation in the field and to assess the effectiveness of the training (Shamoo et al., 1992). The subjects included 3 females and 6 males between 21 to 37 years of age. The tests were conducted in four stages. First, an initial treadmill pretest was conducted indoors at various speeds until the four ventilation levels were experienced by each subject; VR was measured and feedback was given to the subjects. Second, two treadmill training sessions, which involved seven 3-minute segments of varying speeds based on initial tests, were conducted; VR was measured and feedback was given to the subjects. Another similar session was conducted; however, the subjects estimated their own ventilation level during the last 20 seconds of each segment and VR was measured during the last minute of each segment. Immediate feedback was given to the subject's estimate; and the third and fourth stages involved 2 outdoor sessions of 3 hours each. Each hour comprised 15 minutes each of rest, slow walking, jogging, and fast walking. The subjects estimated their own ventilation level at the middle of each segment. The subject's estimate was verified by a respirometer, which measured VR in the middle of each 15-minute activity. No feedback was given to the subject. The overall percent correct score obtained for all ventilation levels was 68% (Shamoo et al., 1992). Therefore, Shamoo et al. (1992) concluded that this training protocol was effective in training subjects to correctly estimate their minute ventilation levels.

For this handbook, inhalation rates were analyzed from the raw data provided by Shamoo et al. (1992). Table 6-36 presents the mean inhalation rates obtained from this analysis at four ventilation levels in two microenvironments (i.e., indoors and outdoors) for all subjects. The mean inhalation rates for all subjects were 0.93, 1.92, 3.01, and 4.80 m^3/hour for low, medium, heavy, and very heavy activities, respectively.

Limitations of this study are its age and the population sample size used in this study was small and was not selected to represent the general U.S. population. The training approach employed may not be cost effective because it was labor intensive; therefore, this approach may not be viable in field studies especially for field studies within large sample sizes.

6.4.7. Spier et al. (1992)—Activity Patterns in Elementary and High School Students Exposed to Oxidant Pollution

Spier et al. (1992) investigated the activity patterns of 17 elementary school students (10−12 years old) and 19 high school students (13−17 years old) in suburban Los Angeles from late September to October (oxidant pollution season). Calibration tests were conducted in supervised outdoor exercise sessions. The exercise sessions consisted of 5 minutes each of rest, slow walking, jogging, and fast walking. HR and VR were measured during the last 2 minutes of each exercise. Individual VR and HR relationships for each individual were determined by fitting a regression line to HR values and log VR values. Each subject recorded their daily activities, changes in location, and breathing rates in diaries for 3 consecutive days. Self-estimated breathing rates were recorded as slow (slow walking), medium (walking faster than normal), and fast (running). HR was recorded once per minute during the 3 days using a Heart Watch. VR values for each self-estimated breathing rate and activity type were estimated from the HR recordings by employing the VR and HR equation obtained from the calibration tests.

The data shown in Table 6-37 represent HR distribution patterns and corresponding predicted VR for each age group during hours spent awake. At the same self-reported activity levels for both age groups, inhalation rates were higher for outdoor activities than for indoor activities. The total number of hours spent indoors was higher for high school students (21.2 hours) than for elementary school students (19.6 hours). The converse was true for outdoor activities: 2.7 hours for high school students and 4.4 hours for elementary school students (see Table 6-38). Table 6-39 describes the distribution patterns of daily inhalation rates for elementary and high school students grouped by activity level.

A limitation of this study is the small sample size. The results may not be representative of all children in these age groups. Another limitation is that the accuracy of the self-estimated breathing rates reported by younger age groups is uncertain. This may affect the validity of the data set generated. An advantage of this study is that inhalation rates were determined for children and adolescents.

6.4.8. Adams (1993)—Measurement of Breathing Rate and Volume in Routinely Performed Daily Activities, Final Report

Adams (1993) conducted research to accomplish two main objectives: (1) identification of mean and ranges of inhalation rates for various age/sex cohorts and specific activities, and (2) derivation of simple linear and multiple regression equations that could be used to predict inhalation rates through other measured variables: breathing frequency (f_B) and oxygen consumption. A total of 160 subjects participated in the primary study. There were four age-dependent groups: (1) children 6 to 12.9 years old, (2) adolescents between 13 and 18.9 years old, (3) adults between 19 and 59.9 years old, and (4) seniors >60 years old (Adams, 1993). An additional 40 children from 6 to 12.9 years old and 12 young children from 3 to 5.9 years old were identified as subjects for pilot testing purposes.

Resting protocols conducted in the laboratory for all age groups consisted of three phases (25 minutes each) of lying, sitting, and standing. The phases were categorized as resting and sedentary activities. Two active protocols—moderate (walking) and heavy (jogging/running) phases—were performed on a treadmill over a progressive continuum of intensity levels made up of 6-minute intervals at three speeds ranging from slow to moderately fast. All protocols involved measuring VR, HR, f_B, and VO_2. Measurements were taken in the last 5 minutes of each phase of the resting protocol and the last 3 minutes of the 6-minute intervals at each speed designated in the active protocols.

In the field, all children completed spontaneous play protocols. The older adolescent population (16 to 18 years) completed car driving and riding, car maintenance (males), and housework (females) protocols. All adult females (19 to 60 years) and most of the senior (60 to 77 years) females completed housework, yardwork, and car driving and riding protocols. Adult and senior males completed car driving and riding, yardwork, and mowing protocols. HR, VR, and f_B were measured during each protocol. Most protocols were conducted for 30 minutes. All the active field protocols were conducted twice.

During all activities in either the laboratory or field protocols, VR for the children's group revealed no significant sex differences, but those for the adult groups demonstrated sex differences. Therefore, inhalation rate (IR) data presented in Table 6-40 and Table 6-41 were categorized as young children, children (no sex), and adult female, and adult male, and adult combined by activity type (lying, sitting, standing, walking, and running). These categorized data from Table 6-40 and Table 6-41 are summarized as inhalation rates in Table 6-42 and Table 6-43. Table 6-42 shows the laboratory protocols. Table 6-43 presents the mean inhalation rates by group and for moderate activity levels in field protocols. A comparison of the data shown in

Table 6-42 and Table 6-43 suggest that during light and sedentary activities in laboratory and field protocols, similar inhalation rates were obtained for adult females and adult males. Accurate predictions of inhalation rates across all population groups and activity types were obtained by including body SA, HR, and breathing frequency in multiple regression analysis (Adams, 1993). Adams (1993) calculated SA from measured height and body weight using the equation:

$$SA = Height^{(0.725)} \times Weight^{(0.425)} \times 71.84 \quad \text{(Eqn. 6-3)}$$

A limitation associated with this study is that the population does not represent the general U.S. population. Also, the classification of activity types (i.e., laboratory and field protocols) into activity levels may bias the inhalation rates obtained for various age/sex cohorts. Age groups for which data are provided are limited and do not conform to U.S. EPA's recommended age groups for children. The estimated rates were based on short-term data and may not reflect long-term patterns.

6.4.9. Layton (1993)—Metabolically Consistent Breathing Rates for Use in Dose Assessments

Layton (1993) presented a method for estimating metabolically consistent inhalation rates for use in quantitative dose assessments of airborne radionuclides. Generally, the approach for estimating the breathing rate for a specified time frame was to calculate a time-weighted-average of ventilation rates associated with physical activities of varying durations. However, in this study, breathing rates were calculated on the basis of oxygen consumption associated with energy expenditures for short (hours) and long (weeks and months) periods of time, using the following general equation to calculate energy-dependent inhalation rates:

$$V_E = E \times H \times VQ \quad \text{(Eqn. 6-4)}$$

where:

V_E = ventilation rate (m^3/minute or m^3/day);
E = energy expenditure rate; [kilojoules/minute (KJ/minute) or megajoules/hour (MJ/hour)];
H = volume of oxygen (at standard temperature and pressure, dry air consumed in the production of 1 kilojoule [KJ] of energy expended [L/KJ or m^3/MJ]); and
VQ = ventilatory equivalent (ratio of minute volume [m^3/minute] to oxygen uptake [m^3/minute]) unitless.

Layton (1993) used three approaches to estimate daily chronic (long term) inhalation rates for different age/sex cohorts of the U.S. population using this methodology.

<u>First Approach</u>

Inhalation rates were estimated by multiplying average daily food-energy intakes (EFDs) for different age/sex cohorts, *H*, and VQ, as shown in the equation above. The average food-energy intake data (see Table 6-44) are based on approximately 30,000 individuals and were obtained from the 1977−1978 USDA-NFCS. The food-energy intakes were adjusted upwards by a constant factor of 1.2 for all individuals 9 years and older. This factor compensated for a consistent bias in USDA-NFCS that was attributed to under-reporting of the foods consumed or the methods used to ascertain dietary intakes. Layton (1993) used a weighted average oxygen uptake of 0.05 L O_2/KJ, which was determined from data reported in the 1977−1978 USDA-NFCS and the second NHANES (NHANES II). The survey sample for NHANES II was approximately 20,000 participants. A VQ of 27 used in the calculations was calculated as the geometric mean of VQ data that were obtained from several studies.

The inhalation rate estimation techniques are shown in the footnotes in Table 6-45. Table 6-46 presents the daily inhalation rate for each age/sex cohort. As shown in Table 6-45, the highest daily inhalation rates were 10 m^3/day for children between the ages of 6 and 8 years, 17 m^3/day for males between 15 and 18 years, and 13 m^3/day for females between 9 and 11 years. Estimated average lifetime inhalation rates for males and females are 14 m^3/day and 10 m^3/day, respectively (see Table 6-45). Inhalation rates were also calculated for active and inactive periods for the various age/sex cohorts.

The inhalation rate for inactive periods was estimated by multiplying the BMR times *H* times VQ. BMR was defined as "the minimum amount of energy required to support basic cellular respiration while at rest and not actively digesting food" (Layton, 1993). The inhalation rate for active periods was calculated by multiplying the inactive inhalation rate by the ratio of the rate of energy expenditure during active hours to the estimated BMR. This ratio is presented as *F* in Table 6-45. Table 6-45 also presents these data for active and inactive inhalation rates. For children, inactive and active inhalation rates ranged from 2.35 to 5.95 m^3/day and from 6.35 to 13.09 m^3/day, respectively. For adult males (19 to 64 years old), the average inactive and active inhalation rates were approximately 10 and 19 m^3/day, respectively. Also, the average inactive and active inhalation rates for adult females (19 to 64 years old) were approximately 8 and 12 m^3/day, respectively.

Second Approach

Inhalation rates were calculated as the product of the BMR of the population cohorts, the ratio of total daily energy expenditure to daily BMR, *H*, and VQ. The BMR data obtained from the literature were statistically analyzed, and regression equations were developed to predict BMR from body weights of various age/sex cohorts. Table 6-46 presents the statistical data used to develop the regression equations. Table 6-47 presents the data obtained from the second approach. Inhalation rates for children (6 months−10 years) ranged from 7.3−9.3 m^3/day for male and 5.6−8.6 m^3/day for female children; for older children (10−18 years), inhalation rates were 15 m^3/day for males and 12 m^3/day for females. Adult females (18 years and older) ranged from 9.9−11 m^3/day and adult males (18 years and older) ranged from 13−17 m^3/day. These rates are similar to the daily inhalation rates obtained using the first approach. Also, the inactive inhalation rates obtained from the first approach are lower than the inhalation rates obtained using the second approach. This may be attributed to the BMR multiplier employed in the equation of the second approach to calculate inhalation rates.

Third Approach

Inhalation rates were calculated by multiplying estimated energy expenditures associated with different levels of physical activity engaged in over the course of an average day by VQ and *H* for each age/sex cohort. The energy expenditure associated with each level of activity was estimated by multiplying BMRs of each activity level by the MET and by the time spent per day performing each activity for each age/sex population. The time-activity data used in this approach were obtained from a survey conducted by Sallis et al. (1985) (Layton, 1993). In that survey, the physical-activity categories and associated MET values used were sleep, MET = 1; light-activity, MET = 1.5; moderate activity, MET = 4; hard activity, MET = 6; and very hard activity, MET = 10. The physical activities were based on recall by the test subject (Layton, 1993). The survey sample was 2,126 individuals (1,120 women and 1,006 men) ages 20−74 years that were randomly selected from four communities in California. The body weights were obtained from a study conducted by Najjar and Rowland (1987) that randomly sampled individuals from the U.S. population (Layton, 1993). Table 6-48 presents the daily inhalation rates (V_E) in m^3/day and m^3/hour for adult males and females aged 20−74 years at five physical activity levels. The total daily inhalation rates ranged from 13−17 m^3/day for adult males and 11−15 m^3/day for adult females.

The rates for adult females were higher when compared with the other two approaches. Layton (1993) reported that the estimated inhalation rates obtained from the third approach were particularly sensitive to the MET value that represented the energy expenditures for light activities. Layton (1993) stated further that in the original time-activity survey [i.e., conducted by Sallis et al. (1985)], time spent performing light activities was not presented. Therefore, the time spent at light activities was estimated by subtracting the total time spent at sleep, moderate, heavy, and very heavy activities from 24 hours (Layton, 1993). The range of inhalation rates for adult females were 9.6−11 m^3/day, 9.9−11 m^3/day, and 11−15 m^3/day, for the first, second, and third approaches, respectively. The inhalation rates for adult males ranged from 13−16 m^3/day for the first approach, and 13−17 m^3/day for the second and third approaches.

Inhalation rates were also obtained for short-term exposures for various age/sex cohorts and five energy-expenditure categories (rest, sedentary, light, moderate, and heavy). BMRs were multiplied by the product of MET, *H*, and VQ. Table 6-49 presents the inhalation-rate data obtained for short-term exposures.

The major strengths of the Layton (1993) study are that it obtains similar results using three different approaches to estimate inhalation rates in different age groups and that the populations are large, consisting of men, women, and children. Explanations for differences in results due to metabolic measurements, reported diet, or activity patterns are supported by observations reported by other investigators in other studies. Major limitations of this study are (1) the estimated activity pattern levels are somewhat subjective; (2) the explanation that activity pattern differences are responsible for the lower level obtained with the metabolic approach (25%) compared to the activity pattern approach is not well supported by the data; and (3) different populations were used in each approach, which may have introduced error.

6.4.10. Linn et al. (1993)—Activity Patterns in Ozone Exposed Construction Workers

Linn et al. (1993) estimated the inhalation rates of 19 construction workers who perform heavy outdoor labor before and during a typical work shift. The workers (laborers, iron workers, and carpenters) were employed at a site on a hospital campus in suburban Los Angeles. The construction site included a new hospital building and a separate medical office complex. The study was conducted between mid-July and early November, 1991. During this period, ozone (O_3) levels were typically high. Initially, each subject was calibrated with a 25-minute exercise test that included slow walking, fast walking, jogging, lifting, and carrying. All calibration tests were conducted in the mornings. VR and HR were measured simultaneously during the test. The data were analyzed using least squares regression to derive an equation for predicting VR at a given HR. Following the calibration tests, each subject recorded the type of activities to be performed during their work shift (i.e., sitting/standing, walking, lifting/carrying, and "working at trade"—defined as tasks specific to the individual's job classification). Location, and self-estimated breathing rates ("slow" similar to slow walking, "medium" similar to fast walking, and "fast" similar to running) were also recorded in the diary. During work, an investigator recorded the diary information dictated by the subjects. HR was recorded minute by minute for each subject before work and during the entire work shift. Thus, VR ranges for each breathing rate and activity category were estimated from the HR recordings by employing the relationship between VR and HR obtained from the calibration tests.

A total of 182 hours of HR recordings were obtained during the survey from the 19 volunteers; 144 hours reflected actual working time according to the diary records. The lowest actual working hours recorded was 6.6 hours, and the highest recorded for a complete work shift was 11.6 hours (Linn et al., 1993). Table 6-50 presents summary statistics for predicted VR distributions for outdoor workers, and for job- or site-defined subgroups. The data reflect all recordings before and during work, and at break times. For all subjects, the mean inhalation rate was 1.68 m^3/hour with a standard deviation of ±0.72 (see Table 6-50). Also, for most subjects, the 1st and 99th percentiles of HR were outside of the calibration range. Therefore, corresponding IR percentiles were extrapolated using the calibration data (Linn et al., 1993).

The data shown in Table 6-51 represent distribution patterns of mean inhalation rate for each subject, total subjects, and job- or site-defined subgroups by self-estimated breathing rates (slow, medium, or fast) or by type of job activity. All data include working and non-working hours. The mean inhalation rates for most individuals showed statistically significant increases with higher self-estimated breathing rates or with increasingly strenuous job activity (Linn et al., 1993). Inhalation rates were higher in hospital site workers when compared with office site workers (see Table 6-51). In spite of their higher predicted VR workers at the hospital site reported a higher percentage of slow breathing time (31%) than workers at the office site (20%), and a lower percentage of fast breathing time, 3% and 5%, respectively (Linn et al., 1993). Therefore, individuals whose work was objectively heavier than average (from VR predictions) tended to describe their work as lighter than average (Linn et al., 1993). Linn et al. (1993) also concluded that during an O_3 pollution episode, construction workers should experience similar microenvironmental O_3 exposure concentrations as other healthy outdoor workers, but with approximately twice as high a VR. Therefore, the inhaled dose of O_3 should be almost two times higher for typical heavy-construction workers than for typical healthy adults performing less strenuous outdoor jobs.

Limitations associated with this study are its age and the small sample size. Another limitation of this study is that calibration data were not obtained at extreme conditions. Therefore, it was necessary to predict inhalation rate values that were outside the calibration range. This may introduce an unknown amount of uncertainty to the data set. Subjective self-estimated breathing rates may be another source of uncertainty in the inhalation rates estimated. An advantage is that this study provides empirical data useful in exposure assessments for a population thought to be the most highly exposed common occupational group (outdoor workers).

6.4.11. Rusconi et al. (1994)—Reference Values for Respiratory Rate in the First 3 Years of Life

Rusconi et al. (1994) examined a large number of infants and children in Milano, Italy, in order to determine the reference values for respiratory rate in children aged 15 days to 3 years. A total of 618 infants and children (336 males and 282 females), who did not have respiratory infections or any severe disease, were included in the study. Of the 618, a total of 309 were in good health and were observed in daycare centers, while the remaining 309 were seen in hospitals or as outpatients.

Respiratory rates were recorded twice, 30 to 60 minutes apart, listening to breath sounds for 60 seconds with a stethoscope, when the child was awake and calm and when the child was sleeping quietly (sleep not associated with any spontaneous movement, including eye movements or vocalizations) (see Table 6-52). The children were assessed for 1 year in order to determine the repeatability of the recordings, to compare respiratory rate counts obtained by stethoscope and by observation, and to construct reference percentile curves by age in a large number of subjects.

The authors plotted the differences between respiratory rate counts determined by stethoscope at 30- to 60-minute intervals against their mean count in waking and sleeping subjects. The standard deviation of the differences between the two counts was 2.5 and 1.7 breaths/minute, respectively, for waking and sleeping children. This standard deviation yielded 95% repeatability coefficients of 4.9 breaths/minute when the infants and children were awake and 3.3 breaths/minute when they were asleep.

In both waking and sleeping states, the respiratory rate counts determined by stethoscope were found to be higher than those obtained by observation. The mean difference was 2.6 and 1.8 breaths per minute, respectively, in waking and sleeping states. The mean respiratory rate counts were significantly higher in infants and children at all ages when awake and calm than when asleep. A decrease in respiratory rate with increasing age was seen in waking and sleeping infants and children. A scatter diagram of respiratory rate counts by age in waking and sleeping subjects showed that the pattern of respiratory rate decline with age was similar in both states, but it was much faster in the first few months of life. The authors constructed centile curves by first log-transforming the data and then applying a second degree polynormal curve, which allowed excellent fitting to observed data. Figure 6-1 and Figure 6-2 show smoothed percentiles by age in waking and sleeping subjects, respectively. The variability of respiratory rate among subjects was higher in the first few months of life, which may be attributable to biological events that occur during these months, such as maturation of the neurologic control of breathing and changes in lung and chest wall compliance and lung volumes.

An advantage of this study is that it provides distribution data for respiratory rate for children from infancy (less than 2 months) to 36 months old. The main limitation of this study is that data are provided in breaths/minute for awake and asleep subjects. Activity pattern data for the awake subjects are limited, which prevents characterization of breathing rates for various levels of exertion. These data are not U.S. data; U.S. distributions were not available. Although, there is no reason to believe that the respiratory rates for Italian children would be different from that of U.S. children, this study only provided data for a narrow range of activities.

6.4.12. Price et al. (2003)—Modeling Interindividual Variation in Physiological Factors Used in PBPK Models of Humans

Price et al. (2003) developed a database of values for physiological parameters often used in physiologically based pharmacokinetic (PBPK) models. The database consisted of approximately 31,000 records containing information on volumes and masses of selected organs and tissues, blood flows for the organ and tissues, and total resting cardiac output and average inhalation rates. Records were created based on data from the NHANES III survey.

The study authors note that the database provides a source of data for human physiological parameters where the parameter values for an individual are correlated with one another and capture interindividual variation in populations of a specific sex, race, and age range. A publicly available computer program, Physiological Parameters for PBPK Modeling, was also developed to randomly retrieve records from the database for groups of individuals of specified age ranges, sex, and ethnicities (Lifeline Group, 2006). Price et al. (2003) recommends that output sets be used as inputs to Monte Carlo-based PBPK models of interindividual variation in dose. A limitation of this study is that these data have not been validated against actual physiological data. Ideally, the database records would have been obtained from detailed physiological analyses of individuals, however, such a survey was not conducted for this study.

6.4.13. Brochu et al. (2006a)—Physiological Daily Inhalation Rates for Free-Living Pregnant and Lactating Adolescents and Women Aged 11 to 55 Years, Using Data From Doubly Labeled Water Measurements for Use in Health Risk Assessment

PDIRs were determined by Brochu et al. (2006a) for underweight, normal-weight, and overweight/obese pregnant and lactating females aged 11 to 55 years using published data on total daily energy expenditures, and energy costs for growth, pregnancy and lactation (breast-energy output and maternal milk-energy synthesis) in free-living females. These data were obtained using the DLW methodology in which disappearance rates of predetermined doses of DLW (^2H_2O and $H_2{}^{18}O$) in urine from non-pregnant and non-lactating females (N = 357) and normal-weight males (N = 131) as well as saliva from gravid and breast-feeding females (N = 91) were monitored by gas-isotope-ratio mass spectrometry.

PDIRs were calculated for underweight, normal-weight, and overweight/obese females aged 11 to 55 years in pre-pregnancy, at Weeks 9, 22, and 36 during pregnancy, and Weeks 6 and 27 postpartum. Weight groups were determined by BMI cutoffs settled by the Institute of Medicine for pre-pregnant females. Underweight, normal-weight, and overweight/obese individuals were defined as those having BMIs lower than 19.8 kg/m^2, between 19.8 and 26 kg/m^2, and greater than 26 kg/m^2, respectively. Parameters used for breast-energy output and the extra energy cost for milk synthesis were 539.29 ± 106.26 kcal/day and 107.86 ± 21.25 kcal/day, respectively. Monte Carlo simulations were necessary to integrate total daily energy requirements of non-pregnant and non-lactating females into energy costs and weight changes at the 9th, 22nd, and 36th weeks of pregnancy and at the 6th and 27th postpartum weeks. A total of 108 sets of 5,000 energetic data were run, resulting in a simulation of 540,000 data, pertaining to 45,000 simulated subjects. Means, standard deviations, and percentiles of energetic values in kcal/day and kcal/kg-day for males and females were converted into PDIRs in m^3/day and m^3/kg-day by using the equation developed by Layton (1993).

Table 6-53, Table 6-54, and Table 6-55 present the distribution of physiological daily inhalation rate percentiles in m^3/day for underweight, normal-weight, and overweight/obese females, respectively, during pregnancy and postpartum weeks. Table 6-56, Table 6-57, and Table 6-58 present physiological daily inhalation rate percentiles in m^3/kg-day for the same categories. PDIRs for under-, normal-, and overweight/obese pregnant and lactating females were higher than those for males reported in Brochu et al. (2006b). In normal-weight subjects, inhalation rates are higher by 18 to 41% throughout pregnancy and 23 to 39% during postpartum weeks: actual values were higher in females by 1.13 to 2.01 m^3/day at the 9th week of pregnancy, 3.74 to 4.53 m^3/day at the 22nd week, and 4.41 to 5.20 m^3/day at the 36th week, and by 4.43 to 5.30 m^3/day at the 6th postpartum week and 4.22 to 5.11 m^3/day at the 27th postpartum week. The highest 99th percentiles were found to be 0.622 m^3/kg-day in pregnant females and 0.647 m^3/kg-day in lactating females. By comparison, the highest 99th percentile value for individuals aged 2.6 months to 96 years was determined to be 0.725 m^3/kg-day (Brochu et al., 2006b). The authors concluded that air quality criteria and standard calculations based on the latter value for non-carcinogenic toxic compounds should, therefore, be protective for virtually all pregnant and lactating females. Brochu et al. (2006a) also noted that the default assumption used by IRIS to derive HECs (total respiratory tract surface of an adult human male of 54.3 m^2 is exposed to a total daily air intake of 20 m^3) would underestimate exposures to pregnant or lactating females since approximately one pregnant or lactating female out of two is exposed to a total daily air intake of 20 m^3 up to the highest 99th percentile of 47.3 m^3.

An advantage of this study is that it includes pregnant and lactating females, and that data are provided for adolescents aged 11 years and older. A limitation of this study is that the study population was partially drawn from Canada and may not represent the general U.S. population. Also, age groups for adolescents for which data are provided do not conform to U.S. EPA's recommended age groups for children.

6.4.14. Allan et al. (2009)—Inhalation Rates for Risk Assessments Involving Construction Workers in Canada

Allan et al. (2009) generated probability density distributions by performing a Monte Carlo simulation to describe inhalation rates for Canadian male and female construction workers. Construction workers in this study were those involved in the construction or physical maintenance of buildings, structures, or other facilities, and their ages ranged from 16 to 65 years. Information regarding activity patterns and/or inhalation rates was obtained from published literature and used to estimate male construction workers' hourly inhalation rates. Female construction worker inhalation rates were estimated using the ratio of general public female-to-male inhalation rates and male construction workers' hourly inhalation rates. Published energy expenditure and inhalation rates were compared by occupation within the construction industry, and these data were used to develop trade-specific scaling factors. All inhalation rates were developed as probability density functions through Monte Carlo simulation. Ten thousand iterations of random sampling were performed, and at the end of the simulation, the results for all 10,000 iterations were summarized into frequency histograms. The mean, standard deviation, and percentiles were calculated based on the frequency counts.

Inhalation rates for male construction workers were represented by a log normal distribution, with a mean rate of 1.40 ± 0.51 m^3/hour. Hourly inhalation rates for female construction workers were scaled down from those of their male counterparts, based on relative awake-time inhalation rates for men and women in the general public. Inhalation rates for female construction workers were also represented by a log normal distribution, with a mean rate of 1.25 ± 0.66 m^3/hour. Construction trade-specific scaling factors were developed and ranged from 0.78 for electricians to 1.11 for ironworkers.

An advantage of this study is that it provides estimated inhalation rates for a population of construction workers. A limitation of this study is that the construction workers in this study were solely male construction workers; no females were among the cohorts monitored.

6.5. REFERENCES FOR CHAPTER 6

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Table 6-4. Distribution Percentiles of Physiological Daily Inhalation Rates (PDIRs) (m^3/day) for Free-Living Normal-Weight Males and Females Aged 2.6 Months to 96 Years											
Age Group (years)	*N*	Body Weight[a] (kg) Mean ± SD	Physiological Daily Inhalation Rates[b] (m^3/day) Mean ± SD	Percentile[c] 5th	10th	25th	50th	75th	90th	95th	99th
Males											
0.22 to <0.5	32	6.7 ± 1.0	3.38 ± 0.72	2.19	2.46	2.89	3.38	3.87	4.30	4.57	5.06
0.5 to <1	40	8.8 ± 1.1	4.22 ± 0.79	2.92	3.21	3.69	4.22	4.75	5.23	5.51	6.05
1 to <2	35	10.6 ± 1.1	5.12 ± 0.88	3.68	3.99	4.53	5.12	5.71	6.25	6.56	7.16
2 to <5	25	15.3 ± 3.4	7.60 ± 1.28	5.49	5.95	6.73	7.60	8.47	9.25	9.71	10.59
5 to <7	96	19.8 ± 2.1	8.64 ± 1.23	6.61	7.06	7.81	8.64	9.47	10.21	10.66	11.50
7 to <11	38	28.9 ± 5.6	10.59 ± 1.99	7.32	8.04	9.25	10.59	11.94	13.14	13.87	15.22
11 to <23	30	58.6 ± 13.9	17.23 ± 3.67	11.19	12.53	14.75	17.23	19.70	21.93	23.26	25.76
23 to <30	34	70.9 ± 6.5	17.48 ± 2.81	12.86	13.88	15.59	17.48	19.38	21.08	22.11	24.02
30 to <40	41	71.5 ± 6.8	16.88 ± 2.50	12.77	13.68	15.20	16.88	18.57	20.09	21.00	22.70
40 to <65	33	71.1 ± 7.2	16.24 ± 2.67	11.84	12.81	14.44	16.24	18.04	19.67	20.64	22.46
65 to ≤96	50	68.9 ± 6.7	12.96 ± 2.48	8.89	9.79	11.29	12.96	14.63	16.13	17.03	18.72
Females											
0.22 to <0.5	53	6.5 ± 0.9	3.26 ± 0.66	2.17	2.41	2.81	3.26	3.71	4.11	4.36	4.81
0.5 to <1	63	8.5 ± 1.0	3.96 ± 0.72	2.78	3.05	3.48	3.96	4.45	4.88	5.14	5.63
1 to <2	66	10.6 ± 1.3	4.78 ± 0.96	3.20	3.55	4.13	4.78	5.43	6.01	6.36	7.02
2 to <5	36	14.4 ± 3.0	7.06 ± 1.16	5.15	5.57	6.28	7.06	7.84	8.54	8.97	9.76
5 to <7	102	19.7 ± 2.3	8.22 ± 1.31	6.06	6.54	7.34	8.22	9.11	9.90	10.38	11.27
7 to <11	161	28.3 ± 4.4	9.84 ± 1.69	7.07	7.68	8.70	9.84	10.98	12.00	12.61	13.76
11 to <23	87	50.0 ± 8.9	13.28 ± 2.60	9.00	9.94	11.52	13.28	15.03	16.61	17.56	19.33
23 to <30	68	59.2 ± 6.6	13.67 ± 2.28	9.91	10.74	12.13	13.67	15.21	16.59	17.42	18.98
30 to <40	59	58.7 ± 5.9	13.68 ± 1.76	10.78	11.42	12.49	13.68	14.87	15.94	16.58	17.78
40 to <65	58	58.8 ± 5.1	12.31 ± 2.07	8.91	9.66	10.92	12.31	13.70	14.96	15.71	17.12
65 to ≤96	45	57.2 ± 7.3	9.80 ± 2.17	6.24	7.02	8.34	9.80	11.27	12.58	13.37	14.85

[a] Measured body weight. Normal-weight individuals defined according to the BMI cut-offs.

[b] Physiological daily inhalation rates were calculated using the following equation: $(TDEE + ECG) \times H \times (V_E/VO_2) \times 10^{-3}$, where H = 0.21 L of O_2/Kcal, V_E/VO_2 = 27 (Layton, 1993) and ECG = stored daily energy cost for growth (kcal/day).

[c] Percentiles based on a normal distribution assumption for age groups.

N = Number of individuals.

SD = Standard deviation.

Source: Brochu et al. (2006b).

Table 6-5. Mean and 95th Percentile Inhalation Rate Values (m^3/day) for Free-Living Normal-Weight Males, Females, and Males and Females Combined

Age Group[a, b]	*N*	Mean[c]	95th, c
Males			
1 to <3 months	32	3.38	4.57
3 to <6 months	32	3.38	4.57
6 to <12 months	40	4.22	5.51
Birth to <1 year	72	3.85	5.09
1 to <2 years	35	5.12	6.56
2 to <3 years	25	7.60	9.71
3 to <6 years	25	7.60	9.71
6 to <11 years	38	10.59	13.87
11 to <16 years	30	17.23	23.26
16 to <21 years	30	17.23	23.26
21 to <31 years	64	17.36	22.65
31 to <41 years	41	16.88	21.00
41 to <51 years	33	16.24	20.64
51 to <61 years	33	16.24	20.64
61 to <71 years	83	14.26	18.47
71 to <81 years	50	12.96	17.03
≥81 years	50	12.96	17.03
Females			
1 to <3 months	53	3.26	4.36
3 to <6 months	53	3.26	4.36
6 to <12 months	63	3.96	5.14
Birth to <1 year	116	3.64	4.78
1 to <2 years	66	4.78	6.36
2 to <3 years	36	7.06	8.97
3 to <6 years	36	7.06	8.97
6 to <11 years	161	9.84	12.61
11 to <16 years	87	13.28	17.56
16 to <21 years	87	13.28	17.56
21 to <31 years	155	13.45	17.50
31 to <41 years	59	13.68	16.58
41 to <51 years	58	12.31	15.71
51 to <61 years	58	12.31	15.71
61 to <71 years	103	11.21	14.69
71 to <81 years	45	9.80	13.37
≥81 years	45	9.80	13.37

Table 6-5. Mean and 95th Percentile Inhalation Rate Values (m^3/day) for Free-Living Normal-Weight Males, Females, and Males and Females Combined (continued)			
Age Group[a,b]	*N*	Mean[c]	95th,c
Males and Females Combined			
1 to <3 months	85	3.31	4.44
3 to <6 months	85	3.31	4.44
6 to <12 months	103	4.06	5.28
Birth to <1 years	188	3.72	4.90
1 to <2 years	101	4.90	6.43
2 to <3 years	61	7.28	9.27
3 to <6 years	61	7.28	9.27
6 to <11 years	199	9.98	12.85
11 to <16 years	117	14.29	19.02
16 to <21 years	117	14.29	19.02
21 to <31 years	219	14.59	19.00
31 to <41 years	100	14.99	18.39
41 to <51 years	91	13.74	17.50
51 to <61 years	91	13.74	17.50
61 to <71 years	186	12.57	16.37
71 to <81 years	95	11.46	15.30
≥81 years	95	11.46	15.30

[a] No other age groups from Table 6-4 (Brochu et al., 2006b) fit into the U.S. EPA age groupings.
[b] See Table 6-25 for concordance with U.S. EPA age groupings.
[c] Weighted (where possible) average of reported study means and 95th percentiles.

N = Number of individuals.

Source: Brochu et al. (2006b).

Table 6-6. Distribution Percentiles of Physiological Daily Inhalation Rates (PDIRs) (m^3/day) for Free-Living Normal-Weight and Overweight/Obese Males and Females Aged 4 to 96 Years

Age Group (years)	*N*	Body Weight[a] (kg) Mean ± SD	Physiological Daily Inhalation Rates[b] (m^3/day)								
			Mean ± SD	Percentile[c] 5th	10th	25th	50th	75th	90th	95th	99th
Males—Normal-weight											
4 to <5.1	77	19.0 ± 1.9	7.90 ± 0.97	6.31	6.66	7.25	7.90	8.56	9.15	9.50	10.16
5.1 to <9.1	52	22.6 ± 3.5	9.14 ± 1.44	6.77	7.29	8.17	9.14	10.11	10.99	11.51	12.49
9.1 to <18.1	36	41.4 ± 12.1	13.69 ± 3.95	7.19	8.63	11.02	13.69	16.35	18.75	20.19	22.88
18.1 to <40.1	98	71.3 ± 6.1	17.41± 2.70	12.96	13.94	15.58	17.41	19.23	20.87	21.85	23.69
40.1 to <70.1	34	70.0 ± 7.8	15.60 ± 2.89	10.85	11.89	13.65	15.60	17.54	19.30	20.34	22.31
70.1 to ≤96	38	68.9 ± 6.8	12.69 ± 2.33	8.85	9.70	11.11	12.69	14.26	15.68	16.53	18.12
Males—Overweight/obese											
4 to <5.1	54	26.5 ± 4.9	9.59 ± 1.26	7.52	7.98	8.74	9.59	10.44	11.21	11.66	12.52
5.1 to <9.1	40	32.5 ± 9.2	10.88 ± 2.49	6.78	7.69	9.20	10.88	12.56	14.07	14.98	16.68
9.1 to <18.1	33	55.8 ± 10.8	14.52 ± 1.98	11.25	11.98	13.18	14.52	15.85	17.06	17.78	19.13
18.1 to <40.1	52	98.1 ± 25.2	20.39 ± 3.62	14.44	15.75	17.95	20.39	22.83	25.03	26.35	28.81
40.1 to <70.1	81	93.2 ± 14.9	17.96 ± 3.71	11.85	13.20	15.45	17.96	20.46	22.71	24.06	26.59
70.1 to ≤96	32	82.3 ± 10.3	14.23 ± 2.94	9.40	10.46	12.25	14.23	16.21	18.00	19.06	21.07
Females—Normal-weight											
4 to <5.1	82	18.7 ± 2.0	7.41 ± 0.91	5.92	6.25	6.80	7.41	8.02	8.57	8.90	9.52
5.1 to <9.1	151	25.5 ± 4.1	9.39 ± 1.62	6.72	7.31	8.30	9.39	10.48	11.47	12.05	13.16
9.1 to <18.1	124	42.7 ± 11.1	12.04 ± 2.86	7.34	8.38	10.11	12.04	13.97	15.70	16.74	18.68
18.1 to <40.1	135	59.1 ± 6.3	13.73 ± 2.01	10.41	11.15	12.37	13.73	15.09	16.31	17.04	18.41
40.1 to <70.1	79	59.1 ± 5.3	11.93 ± 2.16	8.38	9.16	10.47	11.93	13.38	14.69	15.48	16.95
70.1 to ≤96	24	54.8 ± 7.5	8.87 ± 1.79	5.92	6.57	7.66	8.87	10.07	11.16	11.81	13.03
Females—Overweight/obese											
4 to <5.1	56	26.1 ± 5.5	8.70 ± 1.13	6.84	7.26	7.94	8.70	9.47	10.15	10.56	11.33
5.1 to <9.1	68	34.6 ± 9.9	10.55 ± 2.23	6.88	7.69	9.05	10.55	12.06	13.41	14.22	15.75
9.1 to <18.1	68	59.2 ± 12.8	14.27 ± 2.70	9.83	10.81	12.45	14.27	16.09	17.73	18.71	20.55
18.1 to <40.1	76	84.4 ± 16.3	15.66 ± 2.11	12.18	12.95	14.23	15.66	17.08	18.36	19.13	20.57
40.1 to <70.1	91	81.7 ± 17.2	13.01 ± 2.82	8.37	9.40	11.11	13.01	14.91	16.62	17.64	19.56
70.1 to ≤96	28	69.0 ± 7.8	10.00 ± 1.78	7.07	7.71	8.80	10.00	11.20	12.28	12.93	14.14

[a] Measured body weight. Normal-weight and overweight/obese males defined according to the BMI cut-offs.
[b] Physiological daily inhalation rates were calculated using the following equation: $(TDEE + ECG) \times H \times (V_E/VO_2) \times 10^{-3}$, where H = 0.21 L of O_2/Kcal, V_E/VO_2 = 27 (Layton, 1993), *TDEE* = total daily energy expenditure (kcal/day) and *ECG* = stored daily energy cost for growth (kcal/day).
[c] Percentiles based on a normal distribution assumption for age groups.

N = Number of individuals.
SD = Standard deviation.

Source: Brochu et al. (2006b).

Table 6-7. Distribution Percentiles of Physiological Daily Inhalation Rates (PDIRs) per Unit of Body Weight (m^3/kg-day) for Free-Living Normal-Weight Males and Females Aged 2.6 Months to 96 Years

Age Group (years)	Physiological Daily Inhalation Rates[a] (m^3/kg-day)								
		Percentile[b]							
	Mean ± SD	5th	10th	25th	50th	75th	90th	95th	99th
Males									
0.22 to <0.5	0.51 ± 0.09	0.36	0.39	0.45	0.51	0.57	0.63	0.66	0.73
0.5 to <1	0.48 ± 0.07	0.36	0.39	0.43	0.48	0.53	0.57	0.60	0.64
1 to <2	0.48 ± 0.06	0.38	0.41	0.44	0.48	0.52	0.56	0.58	0.62
2 to <5	0.44 ± 0.04	0.38	0.39	0.42	0.44	0.47	0.50	0.51	0.54
5 to <7	0.42 ± 0.05	0.34	0.35	0.38	0.42	0.45	0.48	0.49	0.52
7 to <11	0.37 ± 0.06	0.27	0.29	0.33	0.37	0.41	0.45	0.47	0.52
11 to <23	0.30 ± 0.05	0.22	0.24	0.27	0.30	0.33	0.36	0.38	0.41
23 to <30	0.25 ± 0.04	0.18	0.20	0.22	0.25	0.27	0.30	0.31	0.34
30 to <40	0.24 ± 0.03	0.18	0.19	0.21	0.24	0.26	0.28	0.29	0.32
40 to <65	0.23 ± 0.04	0.16	0.18	0.20	0.23	0.26	0.28	0.30	0.33
65 to ≤96	0.19 ± 0.03	0.14	0.15	0.17	0.19	0.21	0.23	0.24	0.26
Females									
0.22 to <0.5	0.50 ± 0.09	0.35	0.39	0.44	0.50	0.57	0.62	0.66	0.72
0.5 to <1	0.46 ± 0.06	0.36	0.38	0.42	0.46	0.51	0.55	0.57	0.61
1 to <2	0.45 ± 0.08	0.33	0.35	0.40	0.45	0.50	0.55	0.58	0.63
2 to <5	0.44 ± 0.07	0.32	0.35	0.39	0.44	0.49	0.53	0.56	0.61
5 to <7	0.40 ± 0.05	0.32	0.33	0.36	0.40	0.43	0.46	0.47	0.51
7 to <11	0.35 ± 0.06	0.25	0.27	0.31	0.35	0.39	0.43	0.45	0.50
11 to <23	0.27 ± 0.05	0.19	0.21	0.24	0.27	0.30	0.33	0.35	0.38
23 to <30	0.23 ± 0.04	0.16	0.18	0.20	0.23	0.26	0.29	0.30	0.33
30 to <40	0.24 ± 0.04	0.18	0.19	0.21	0.24	0.26	0.28	0.29	0.32
40 to <65	0.21 ± 0.04	0.15	0.16	0.19	0.21	0.24	0.26	0.27	0.30
65 to ≤96	0.17 ± 0.04	0.11	0.13	0.15	0.17	0.20	0.22	0.23	0.26

[a] Physiological daily inhalation rates were calculated using the following equation: $(TDEE + ECG) \times H \times (V_E/VO_2) \times 10^{-3}$, where H = 0.21 L of O_2/Kcal, V_E/VO_2 = 27 (Layton, 1993), $TDEE$ = total daily energy expenditure (kcal/day) and ECG = stored daily energy cost for growth (kcal/day).

[b] Percentiles based on a normal distribution assumption for age groups.

SD = Standard deviation.

Source: Brochu et al. (2006b).

Table 6-8. Distribution Percentiles of Physiological Daily Inhalation Rates (PDIRs) (m^3/kg-day) for Free-Living Normal-Weight and Overweight/Obese Males and Females Aged 4 to 96 Years

Age Group (years)	Physiological Daily Inhalation Rates[a] (m^3/kg-day)								
		Percentile[b]							
	Mean ± SD	5th	10th	25th	50th	75th	90th	95th	99th
Males—Normal-weight									
4 to <5.1	0.42 ± 0.04	0.35	0.36	0.39	0.42	0.45	0.47	0.49	0.52
5.1 to <9.1	0.41 ± 0.06	0.31	0.34	0.37	0.41	0.45	0.48	0.50	0.54
9.1 to <18.1	0.33 ± 0.05	0.26	0.27	0.30	0.33	0.37	0.40	0.41	0.45
18.1 to <40.1	0.25± 0.04	0.18	0.20	0.22	0.25	0.27	0.29	0.31	0.33
40.1 to <70.1	0.22 ± 0.04	0.16	0.17	0.20	0.22	0.25	0.28	0.29	0.32
70.1 to ≤96	0.19 ± 0.03	0.13	0.14	0.16	0.19	0.21	0.23	0.24	0.26
Males—Overweight/obese									
4 to <5.1	0.37 ± 0.04	0.30	0.31	0.34	0.37	0.40	0.42	0.44	0.47
5.1 to <9.1	0.35 ± 0.08	0.22	0.25	0.29	0.35	0.40	0.45	0.47	0.53
9.1 to <18.1	0.27 ± 0.04	0.20	0.22	0.24	0.27	0.29	0.32	0.33	0.36
18.1 to <40.1	0.21 ± 0.04	0.15	0.17	0.19	0.21	0.22	0.26	0.27	0.30
40.1 to <70.1	0.19 ± 0.03	0.14	0.15	0.17	0.19	0.22	0.24	0.25	0.28
70.1 to ≤96	0.17 ± 0.03	0.12	0.13	0.15	0.17	0.19	0.21	0.22	0.24
Females—Normal-weight									
4 to <5.1	0.40 ± 0.05	0.32	0.34	0.37	0.40	0.43	0.46	0.48	0.51
5.1 to <9.1	0.37 ± 0.06	0.27	0.29	0.33	0.37	0.41	0.45	0.47	0.52
9.1 to <18.1	0.29 ± 0.06	0.20	0.22	0.25	0.29	0.33	0.36	0.38	0.42
18.1 to <40.1	0.23 ± 0.04	0.17	0.19	0.21	0.23	0.26	0.28	0. 30	0.32
40.1 to <70.1	0.20 ± 0.04	0.14	0.15	0.18	0.20	0.23	0.25	0.27	0.29
70.1 to ≤96	0.16 ± 0.04	0.11	0.12	0.14	0.16	0.19	0.20	0.22	0.24
Females—Overweight/obese									
4 to <5.1	0.34 ± 0.04	0.27	0.28	0.31	0.34	0.37	0.40	0.41	0.44
5.1 to <9.1	0.32 ± 0.07	0.21	0.23	0.27	0.32	0.36	0.40	0.43	0.47
9.1 to <18.1	0.25 ± 0.05	0.17	0.18	0.21	0.25	0.28	0.31	0.33	0.36
18.1 to <40.1	0.19 ± 0.03	0.14	0.15	0.17	0.19	0.21	0.22	0.23	0.25
40.1 to <70.1	0.16 ± 0.03	0.11	0.12	0.14	0.16	0.18	0.20	0.21	0.23
70.1 to ≤96	0.15 ± 0.03	0.10	0.11	0.13	0.15	0.16	0.18	0.19	0.21

[a] Physiological daily inhalation rates were calculated using the following equation: ($TDEE + ECG$) × H × (V_E/VO_2) × 10^{-3}, where H = 0.21 L of O_2/Kcal, V_E/VO_2 = 27 (Layton, 1993), $TDEE$ = total daily energy expenditure (kcal/day) and ECG = stored daily energy cost for growth (kcal/day).

[b] Percentiles based on a normal distribution assumption for age groups.

SD = Standard deviation.

Source: Brochu et al. (2006b).

Table 6-9. Physiological Daily Inhalation Rates (PDIRs) for Newborns Aged 1 Month or Less

Age Group	*N*	Body Weight (kg) Mean ± SD	Physiological Daily Inhalation Rates[a] Mean ± SD (m^3/day)	
			(m^3/day)	(m^3/kg-day)
21 days (3 weeks)	13[b,c]	1.2 ± 0.2	0.85 ± 0.17[d]	0.74 ± 0.09[d]
32 days (~1 month)	10[e,f]	4.7 ± 0.7	2.45 ± 0.59[g]	0.53 ± 0.10[g]
33 days (~1 month)	10[b,f]	4.8 ± 0.3	2.99 ± 0.47[g]	0.62 ±0.09[g]

[a] Physiological daily inhalation rates were calculated using the following equation: $(TDEE + ECG) \times H \times (V_E/VO_2) \times 10^{-3}$, where H = 0.21 L of O_2/Kcal, V_E/VO_2 = 27 (Layton, 1993), *TDEE* = total daily energy expenditure (kcal/day) and *ECG* = stored daily energy cost for growth (kcal/day).

[b] Formula-fed infants.

[c] Healthy infants with very low birth weight.

[d] TDEEs based on nutritional balance measurements during 3-day periods.

[e] Breast-fed infants.

[f] Infants evaluated as being clinically healthy and neither underweight or overweight.

[g] TDEEs based on ^2H_2O and $H_2{}^{18}O$ disappearance rates from urine.

N = Number of individuals.
SD = Standard deviation.

Source: Brochu et al. (2006b).

Table 6-10. Non-Normalized Daily Inhalation Rates (m^3/day) Derived Using Layton's (1993) Method and CSFII Energy Intake Data

Age	Sample Size (Non-Weighted)	Mean	SEM	Percentiles 50th	90th	95th	SE of 95th Percentile
Infancy							
0 to 2 months	182	3.63	0.14	3.30	5.44	7.10	0.64
3 to 5 months	294	4.92	0.14	4.56	6.86	7.72	0.48
6 to 8 months	261	6.09	0.15	5.67	8.38	9.76	0.86
9 to 11 months	283	7.41	0.20	6.96	10.21	11.77	-
0 to 11 months	1,020	5.70	0.10	5.32	8.74	9.95	0.55
Children							
1 year	934	8.77	0.08	8.30	12.19	13.79	0.25
2 years	989	9.76	0.10	9.38	13.56	14.81	0.35
3 years	1,644	10.64	0.10	10.28	14.59	16.03	0.27
4 years	1,673	11.40	0.09	11.05	15.53	17.57	0.23
5 years	790	12.07	0.13	11.56	15.72	18.26	0.47
6 years	525	12.25	0.18	11.95	16.34	17.97	0.87
7 years	270	12.86	0.21	12.51	16.96	19.06	1.27
8 years	253	13.05	0.25	12.42	17.46	19.02	1.08
9 years	271	14.93	0.29	14.45	19.68	22.45[a]	1.35
10 years	234	15.37	0.35	15.19	20.87	22.90[a]	1.02
11 years	233	15.49	0.32	15.07	21.04	23.91[a]	1.62
12 years	170	17.59	0.54	17.11	25.07[a]	29.17[a]	1.61
13 years	194	15.87	0.44	14.92	22.81[a]	26.23[a]	1.11
14 years	193	17.87	0.62	15.90	25.75[a]	29.45[a]	4.38
15 years	185	18.55	0.55	17.91	28.11[a]	29.93[a]	1.79
16 years	201	18.34	0.54	17.37	27.56	31.01	2.07
17 years	159	17.98	0.96	15.90	31.42[a]	36.69[a]	-
18 years	135	18.59	0.78	17.34	28.80[a]	35.24[a]	4.24
Adolescent Boys							
9 to 18 years	983	19.27	0.28	17.96	28.78	32.82	1.39
Adolescent Girls							
9 to 18 years	992	14.27	0.22	13.99	21.17	23.30	0.61
U.S. EPA Cancer Guidelines' Age Groups with Greater Weighting							
0 through 1 year	1,954	7.50	0.08	7.19	11.50	12.86	0.17
2 through 15 years	7,624	14.09	0.12	13.13	20.99	23.88	0.50

[a] FASEB/LSRO (1995) convention, adopted by CSFII, denotes a value that might be less statistically reliable than other estimates due to small cell size.

\- Denotes unable to calculate.

SEM = Standard error of the mean.
SE = Standard error.

Source: Arcus-Arth and Blaisdell (2007).

Table 6-11. Mean and 95th Percentile Inhalation Rate Values (m^3/day) for Males and Females Combined

Age Group[a,b]	Sample Size	Mean[c]	95th,c
Birth to <1 month	182	3.63	7.10
1 to <3 months	182	3.63	7.10
3 to <6 months	294	4.92	7.72
6 to <12 months	544	6.78	10.81
Birth to <1 year	1,020	5.70	9.95
1 to <2 years	934	8.77	13.79
2 to <3 years	989	9.76	14.81
3 to <6 years	4,107	11.22	17.09
6 to <11 years	1,553	13.42	19.86
11 to <16 years	975	16.98	27.53
16 to <21 years	495	18.29	33.99

[a] No other age groups from Table 6-10 (Arcus-Arth and Blaisdell, 2007) fit into the U.S. EPA age groupings.

[b] See Table 6-25 for concordance with U.S. EPA age groupings.

[c] Weighted (where possible) average of reported study means and 95th percentiles.

Source: Arcus-Arth and Blaisdell (2007).

Table 6-12. Summary of Institute of Medicine (IOM) Energy Expenditure Recommendations for Active and Very Active People With Equivalent Inhalation Rates

	Males		Females	
Age (years)	Energy Expenditure (kcal/day)	Inhalation Rate (m^3/day)	Energy Expenditure (kcal/day)	Inhalation Rate (m^3/day)
<1	607	3.4	607	3.4
1	869	4.9	869	4.9
2	1,050	5.9	977	5.5
3	1,485−1,683	8.4−9.5	1,395−1,649	7.9−9.3
4	1,566−1,783	8.8−10.1	1,475−1,750	8.3−9.9
5	1,658−1,894	9.4−10.7	1,557−1,854	8.8−10.5
6	1,742−1,997	9.8−11.3	1,642−1,961	9.3−11.1
7	1,840−2,115	10.4−11.9	1,719−2,058	9.7−11.6
8	1,931−2,225	10.9−12.6	1,810−2,173	10.2−12.3
9	2,043−2,359	11.5−13.3	1,890−2,273	10.7−12.8
10	2,149−2,486	12.1−14.0	1,972−2,376	11.1−13.4
11	2,279−2,640	12.9−14.9	2,071−2,500	11.7−14.1
12	2,428−2,817	13.7−15.9	2,183−2,640	12.3−14.9
13	2,618−3,038	14.8−17.2	2,281−2,762	12.9−15.6
14	2,829−3,283	16.0−18.5	2,334−2,831	13.2−16.0
15	3,013−3,499	17.0−19.8	2,362−2,870	13.3−16.2
16	3,152−3,663	17.8−20.7	2,368−2,883	13.4−16.3
17	3,226−3,754	18.2−21.2	2,353−2,871	13.3−16.2
18	2,823−3,804	18.4−21.5	2,336−2,858	13.2−16.1
19 to 30	3,015−3,490	17.0−19.7	2,373−2,683	13.4−15.2
31 to 50	2,862−3,338	16.2−18.9	2,263−2,573	12.8−14.5
51 to 70	2,671−3,147	15.1−17.8	2,124−2,435	12.0−13.8

Source: Stifelman (2007).

Table 6-13. Mean Inhalation Rate Values (m^3/day) for Males, Females, and Males and Females Combined[a]

Age Group[b,c] (years)	Males[d]	Females[d]	Combined[d]
Birth to <1	3.4	3.4	3.4
1 to <2	4.9	4.9	4.9
2 to <3	5.9	5.5	5.7
3 to <6	9.5	9.1	9.3
6 to <11	11.8	11.2	11.5
11 to <16	16.1	14.0	15.0
16 to <21	19.3	14.6	17.0
21 to <31	18.4	14.3	16.3
31 to <41	17.6	13.7	15.6
41 to <51	17.6	13.7	15.6
51 to <61	16.5	12.9	14.7
61 to <71	16.5	12.9	14.7

[a] Inhalation rates are for IOM Physical Activity Level (PAL) category “active”; the total number of subjects for all PAL categories was 3,007. Sample sizes were not reported.
[b] Age groups from Table 6-12 were regrouped to fit into the U.S. EPA age groupings.
[c] See Table 6-25 for concordance with U.S. EPA age groupings.
[d] Weighted (where possible) average of reported study means.

Source: Stifelman (2007).

Table 6-14. Descriptive Statistics for Daily Average Inhalation Rate in Males, by Age Category[a]

Age Group (years)	*N*	Daily Average Inhalation Rate, Unadjusted for Body Weight (m³/day)								
		Mean	Percentiles							Maximum
			5th	10th	25th	50th	75th	90th	95th	
Birth to <1	419	8.76	4.78	5.70	7.16	8.70	10.43	11.92	12.69	17.05
1 to <2	308	13.49	9.73	10.41	11.65	13.12	15.02	17.02	17.90	24.24
2 to <3	261	13.23	9.45	10.21	11.43	13.19	14.50	16.27	17.71	28.17
3 to <6	540	12.64	10.43	10.87	11.39	12.59	13.64	14.63	15.41	19.53
6 to <11	940	13.42	10.08	10.68	11.74	13.09	14.73	16.56	17.73	24.97
11 to <16	1,337	15.32	11.40	12.11	13.28	14.79	16.82	19.54	21.21	28.54
16 to <21	1,241	17.21	12.60	13.41	14.49	16.63	19.17	21.93	23.37	39.21
21 to <31	701	18.82	12.69	13.56	15.49	18.17	21.24	24.57	27.13	43.42
31 to <41	728	20.29	14.00	14.96	16.96	19.83	23.01	26.77	28.90	40.72
41 to <51	753	20.94	14.66	15.54	17.50	20.59	23.89	26.71	28.37	45.98
51 to <61	627	20.91	14.99	16.07	17.60	20.40	23.16	27.01	29.09	38.17
61 to <71	678	17.94	13.91	14.50	15.88	17.60	19.54	21.77	23.50	28.09
71 to <81	496	16.34	13.10	13.61	14.66	16.23	17.57	19.43	20.42	24.52
≥81	255	15.15	11.95	12.57	13.82	14.90	16.32	18.01	18.69	22.64
Age Group (years)	*N*	Daily Average Inhalation Rate, Adjusted for Body Weight (m³/day-kg)								
		Mean	Percentiles							Maximum
			5th	10th	25th	50th	75th	90th	95th	
Birth to <1	419	1.09	0.91	0.94	1.00	1.09	1.16	1.26	1.29	1.48
1 to <2	308	1.19	0.96	1.02	1.09	1.17	1.26	1.37	1.48	1.73
2 to <3	261	0.95	0.78	0.82	0.87	0.94	1.01	1.09	1.13	1.36
3 to <6	540	0.70	0.52	0.56	0.61	0.69	0.78	0.87	0.92	1.08
6 to <11	940	0.44	0.32	0.34	0.38	0.43	0.50	0.55	0.58	0.80
11 to <16	1,337	0.29	0.21	0.22	0.25	0.28	0.32	0.36	0.38	0.51
16 to <21	1,241	0.23	0.17	0.18	0.20	0.23	0.25	0.28	0.30	0.39
21 to <31	701	0.23	0.16	0.17	0.19	0.22	0.26	0.30	0.32	0.51
31 to <41	728	0.24	0.16	0.18	0.20	0.23	0.27	0.31	0.34	0.46
41 to <51	753	0.24	0.17	0.18	0.20	0.23	0.28	0.32	0.34	0.47
51 to <61	627	0.24	0.16	0.18	0.20	0.24	0.27	0.30	0.34	0.43
61 to <71	678	0.21	0.17	0.18	0.19	0.20	0.22	0.24	0.25	0.32
71 to <81	496	0.20	0.17	0.18	0.19	0.20	0.21	0.23	0.24	0.31
≥81	255	0.20	0.17	0.18	0.19	0.20	0.22	0.23	0.25	0.28

[a] Individual daily averages are weighted by their 4-year sampling weights as assigned within NHANES 1999−2002 when calculating the statistics in this table. Inhalation rate was estimated using a multiple linear regression model.

N = Number of individuals.
BW = Body weight.

Source: U.S. EPA (2009a).

Table 6-15. Descriptive Statistics for Daily Average Inhalation Rate in Females, by Age Category[a]

Age Group (years)	*N*	Daily Average Inhalation Rate, Unadjusted for Body Weight (m³/day) Mean	Percentiles 5th	10th	25th	50th	75th	90th	95th	Maximum
Birth to <1	415	8.52	4.84	5.49	6.84	8.41	9.78	11.65	12.66	26.25
1	245	13.31	9.09	10.12	11.25	13.03	14.64	17.45	18.62	24.77
2	255	12.74	8.91	10.07	11.38	12.60	13.95	15.58	16.36	23.01
3 to <6	543	12.17	9.88	10.38	11.20	12.02	13.02	14.03	14.93	19.74
6 to <11	894	12.41	9.99	10.35	11.02	11.95	13.42	15.13	16.34	20.82
11 to <16	1,451	13.44	10.47	11.12	12.04	13.08	14.54	16.26	17.41	26.58
16 to <21	1,182	13.59	9.86	10.61	11.78	13.20	15.02	17.12	18.29	30.11
21 to <31	1,023	14.57	10.15	10.67	11.94	14.10	16.62	19.32	21.14	30.23
31 to <41	869	14.98	11.07	11.81	13.02	14.69	16.32	18.50	20.45	28.28
41 to <51	763	16.20	12.11	12.57	14.16	15.88	17.96	19.92	21.34	35.88
51 to <61	622	16.19	12.33	12.96	14.07	15.90	17.80	19.93	21.21	25.70
61 to <71	700	12.99	10.40	10.77	11.78	12.92	13.91	15.39	16.14	20.33
71 to <81	470	12.04	9.89	10.20	10.89	11.82	12.96	14.11	15.19	17.70
≥81	306	11.15	9.19	9.46	10.14	11.02	11.87	12.84	13.94	16.93
		Daily Average Inhalation Rate, Adjusted for Body Weight (m³/day-kg)								
Age Group (years)	*N*	Mean	Percentiles 5th	10th	25th	50th	75th	90th	95th	Maximum
Birth to <1	415	1.14	0.91	0.97	1.04	1.13	1.24	1.33	1.38	1.60
1	245	1.20	0.97	1.01	1.10	1.18	1.30	1.41	1.46	1.73
2	255	0.95	0.82	0.84	0.89	0.96	1.01	1.07	1.10	1.23
3 to <6	543	0.69	0.48	0.54	0.60	0.68	0.77	0.88	0.92	1.12
6 to <11	894	0.43	0.28	0.31	0.36	0.43	0.49	0.55	0.58	0.75
11 to <16	1,451	0.25	0.19	0.20	0.22	0.24	0.28	0.31	0.34	0.47
16 to <21	1,182	0.21	0.16	0.17	0.19	0.21	0.23	0.27	0.28	0.36
21 to <31	1,023	0.21	0.14	0.16	0.18	0.20	0.23	0.26	0.28	0.40
31 to <41	869	0.21	0.14	0.15	0.18	0.20	0.23	0.27	0.30	0.43
41 to <51	763	0.22	0.15	0.16	0.19	0.21	0.25	0.28	0.31	0.41
51 to <61	622	0.22	0.15	0.16	0.18	0.21	0.24	0.28	0.30	0.40
61 to <71	700	0.18	0.14	0.15	0.16	0.17	0.19	0.21	0.22	0.27
71 to <81	470	0.18	0.14	0.15	0.16	0.17	0.19	0.21	0.23	0.34
≥81	306	0.18	0.14	0.15	0.16	0.18	0.20	0.21	0.22	0.28

[a] Individual daily averages are weighted by their 4-year sampling weights as assigned within NHANES 1999−2002 when calculating the statistics in this table. Inhalation rate was estimated using a multiple linear regression model.

N = Number of individuals.

Source: U.S. EPA (2009a)

Table 6-16. Mean and 95th Percentile Inhalation Rate Values (m^3/day) for Males, Females, and Males and Females Combined

Age Group (years)	*N*	Mean	95th
Males			
Birth to <1	419	8.76	12.69
1 to <2	308	13.49	17.90
2 to <3	261	13.23	17.71
3 to <6	540	12.64	15.41
6 to <11	940	13.42	17.73
11 to <16	1,337	15.32	21.21
16 to <21	1,241	17.21	23.37
21 to <31	701	18.82	27.13
31 to <41	728	20.29	28.90
41 to <51	753	20.94	28.37
51 to <61	627	20.91	29.09
61 to <71	678	17.94	23.50
71 to <81	496	16.34	20.42
≥81	255	15.15	18.69
Females			
Birth to <1	415	8.52	12.66
1 to <2	245	13.31	18.62
2 to <3	255	12.74	16.36
3 to <6	543	12.17	14.93
6 to <11	894	12.41	16.34
11 to <16	1,451	13.44	17.41
16 to <21	1,182	13.59	18.29
21 to <31	1,023	14.57	21.14
31 to <41	869	14.98	20.45
41 to <51	763	16.20	21.34
51 to <61	622	16.19	21.21
61 to <71	700	12.99	16.14
71 to <81	470	12.04	15.19
≥81	306	11.15	13.94

Table 6-16. Mean and 95th Percentile Inhalation Rate Values (m^3/day) for Males, Females, and Males and Females Combined (continued)

Age Group (years)	*N*	Mean	95th
Males and Females Combined[a]			
Birth to <1	834	8.64	12.67
1 to <2	553	13.41	18.22
2 to <3	516	12.99	17.04
3 to <6	1,083	12.40	15.17
6 to <11	1,834	12.93	17.05
11 to <16	2,788	14.34	19.23
16 to <21	2,423	15.44	20.89
21 to <31	1,724	16.30	23.57
31 to <41	1,597	17.40	24.30
41 to <51	1,516	18.55	24.83
51 to <61	1,249	18.56	25.17
61 to <71	1,378	15.43	19.76
71 to <81	966	14.25	17.88
≥81	561	12.97	16.10

[a] Weighted average of reported male and female means and 95th percentiles.

N = Number of individuals.

Source: U.S. EPA (2009a).

Table 6-17. Descriptive Statistics for Average Ventilation Rate,[a] Unadjusted for Body Weight, While Performing Activities Within the Specified Activity Category, for Males by Age Category

Age Group (years)	*N*	Mean	Average Ventilation Rate (m^3/minute) Percentiles 5th	10th	25th	50th	75th	90th	95th	Maximum
Sleep or nap (Activity ID = 14500)										
Birth to <1	419	3.08E−03	1.66E−03	1.91E−03	2.45E−03	3.00E−03	3.68E−03	4.35E−03	4.77E−03	7.19E−03
1	308	4.50E−03	3.11E−03	3.27E−03	3.78E−03	4.35E−03	4.95E−03	5.90E−03	6.44E−03	1.00E−02
2	261	4.61E−03	3.01E−03	3.36E−03	3.94E−03	4.49E−03	5.21E−03	6.05E−03	6.73E−03	8.96E−03
3 to <6	540	4.36E−03	3.06E−03	3.30E−03	3.76E−03	4.29E−03	4.86E−03	5.54E−03	5.92E−03	7.67E−03
6 to <11	940	4.61E−03	3.14E−03	3.39E−03	3.83E−03	4.46E−03	5.21E−03	6.01E−03	6.54E−03	9.94E−03
11 to <16	1,337	5.26E−03	3.53E−03	3.78E−03	4.34E−03	5.06E−03	5.91E−03	6.94E−03	7.81E−03	1.15E−02
16 to <21	1,241	5.31E−03	3.55E−03	3.85E−03	4.35E−03	5.15E−03	6.09E−03	6.92E−03	7.60E−03	1.28E−02
21 to <31	701	4.73E−03	3.16E−03	3.35E−03	3.84E−03	4.56E−03	5.42E−03	6.26E−03	6.91E−03	1.12E−02
31 to <41	728	5.16E−03	3.37E−03	3.62E−03	4.23E−03	5.01E−03	5.84E−03	6.81E−03	7.46E−03	1.09E−02
41 to <51	753	5.65E−03	3.74E−03	4.09E−03	4.73E−03	5.53E−03	6.47E−03	7.41E−03	7.84E−03	1.08E−02
51 to <61	627	5.78E−03	3.96E−03	4.20E−03	4.78E−03	5.57E−03	6.54E−03	7.74E−03	8.26E−03	1.18E−02
61 to <71	678	5.98E−03	4.36E−03	4.57E−03	5.13E−03	5.81E−03	6.68E−03	7.45E−03	7.93E−03	1.23E−02
71 to <81	496	6.07E−03	4.26E−03	4.55E−03	5.17E−03	6.00E−03	6.77E−03	7.65E−03	8.33E−03	1.05E−02
≥81	255	5.97E−03	4.20E−03	4.49E−03	5.23E−03	5.90E−03	6.68E−03	7.36E−03	7.76E−03	1.00E−02
Sedentary and Passive Activities (METS ≤1.5—Includes Sleep or Nap)										
Birth to <1	419	3.18E−03	1.74E−03	1.99E−03	2.50E−03	3.10E−03	3.80E−03	4.40E−03	4.88E−03	7.09E−03
1	308	4.62E−03	3.17E−03	3.50E−03	3.91E−03	4.49E−03	5.03E−03	5.95E−03	6.44E−03	9.91E−03
2	261	4.79E−03	3.25E−03	3.66E−03	4.10E−03	4.69E−03	5.35E−03	6.05E−03	6.71E−03	9.09E−03
3 to <6	540	4.58E−03	3.47E−03	3.63E−03	4.07E−03	4.56E−03	5.03E−03	5.58E−03	5.82E−03	7.60E−03
6 to <11	940	4.87E−03	3.55E−03	3.78E−03	4.18E−03	4.72E−03	5.40E−03	6.03E−03	6.58E−03	9.47E−03
11 to <16	1,337	5.64E−03	4.03E−03	4.30E−03	4.79E−03	5.43E−03	6.26E−03	7.20E−03	7.87E−03	1.11E−02

Table 6-17. Descriptive Statistics for Average Ventilation Rate,[a] Unadjusted for Body Weight, While Performing Activities Within the Specified Activity Category, for Males by Age Category (continued)

Age Group (years)	N	Mean	Average Ventilation Rate (m^3/minute) Percentiles 5th	10th	25th	50th	75th	90th	95th	Maximum
16 to <21	1,241	5.76E−03	4.17E−03	4.42E−03	4.93E−03	5.60E−03	6.43E−03	7.15E−03	7.76E−03	1.35E−02
21 to <31	701	5.11E−03	3.76E−03	3.99E−03	4.33E−03	5.00E−03	5.64E−03	6.42E−03	6.98E−03	1.03E−02
31 to <41	728	5.57E−03	3.99E−03	4.42E−03	4.86E−03	5.45E−03	6.17E−03	6.99E−03	7.43E−03	1.00E−02
41 to <51	753	6.11E−03	4.65E−03	4.92E−03	5.37E−03	6.02E−03	6.65E−03	7.46E−03	7.77E−03	1.05E−02
51 to <61	627	6.27E−03	4.68E−03	5.06E−03	5.50E−03	6.16E−03	6.89E−03	7.60E−03	8.14E−03	1.04E−02
61 to <71	678	6.54E−03	5.02E−03	5.31E−03	5.85E−03	6.47E−03	7.12E−03	7.87E−03	8.22E−03	1.09E−02
71 to <81	496	6.65E−03	5.26E−03	5.55E−03	5.96E−03	6.59E−03	7.18E−03	7.81E−03	8.26E−03	9.9E−03
≥81	255	6.44E−03	5.09E−03	5.37E−03	5.82E−03	6.43E−03	7.01E−03	7.57E−03	7.90E−03	9.13E−03
Light Intensity Activities (1.5< METS ≤3.0)										
Birth to <1	419	7.94E−03	4.15E−03	5.06E−03	6.16E−03	7.95E−03	9.57E−03	1.08E−02	1.19E−02	1.55E−02
1	308	1.16E−02	8.66E−03	8.99E−03	9.89E−03	1.14E−02	1.29E−02	1.44E−02	1.58E−02	2.11E−02
2	261	1.17E−02	8.52E−03	9.14E−03	9.96E−03	1.14E−02	1.30E−02	1.47E−02	1.53E−02	1.90E−02
3 to <6	540	1.14E−02	9.20E−03	9.55E−03	1.02E−02	1.11E−02	1.23E−02	1.34E−02	1.40E−02	1.97E−02
6 to <11	940	1.16E−02	8.95E−03	9.33E−03	1.02E−02	1.13E−02	1.28E−02	1.46E−02	1.56E−02	2.18E−02
11 to <16	1,337	1.32E−02	9.78E−03	1.03E−02	1.13E−02	1.28E−02	1.47E−02	1.64E−02	1.87E−02	2.69E−02
16 to <21	1,241	1.34E−02	1.00E−02	1.05E−02	1.15E−02	1.30E−02	1.50E−02	1.70E−02	1.80E−02	2.91E−02
21 to <31	701	1.30E−02	9.68E−03	1.02E−02	1.13E−02	1.24E−02	1.40E−02	1.65E−02	1.77E−02	2.72E−02
31 to <41	728	1.36E−02	1.06E−02	1.11E−02	1.20E−02	1.33E−02	1.48E−02	1.65E−02	1.81E−02	2.55E−02
41 to <51	753	1.44E−02	1.12E−02	1.18E−02	1.30E−02	1.41E−02	1.56E−02	1.74E−02	1.83E−02	2.30E−02
51 to <61	627	1.46E−02	1.11E−02	1.16E−02	1.30E−02	1.44E−02	1.59E−02	1.80E−02	1.94E−02	2.55E−02
61 to <71	678	1.41E−02	1.11E−02	1.17E−02	1.27E−02	1.39E−02	1.54E−02	1.69E−02	1.80E−02	2.05E−02
71 to <81	496	1.39E−02	1.12E−02	1.17E−02	1.27E−02	1.37E−02	1.50E−02	1.62E−02	1.69E−02	2.00E−02
≥81	255	1.38E−02	1.10E−02	1.17E−02	1.26E−02	1.38E−02	1.47E−02	1.60E−02	1.67E−02	2.07E−02

Table 6-17. Descriptive Statistics for Average Ventilation Rate,[a] Unadjusted for Body Weight, While Performing Activities Within the Specified Activity Category, for Males by Age Category (continued)

Age Group (years)	N	Mean	Average Ventilation Rate (m^3/minute)							Maximum
			Percentiles							
			5th	10th	25th	50th	75th	90th	95th	
Moderate Intensity Activities (3.0< METS ≤6.0)										
Birth to <1	419	1.45E−02	7.41E−03	8.81E−03	1.15E−02	1.44E−02	1.70E−02	2.01E−02	2.25E−02	3.05E−02
1	308	2.14E−02	1.45E−02	1.59E−02	1.80E−02	2.06E−02	2.41E−02	2.69E−02	2.89E−02	3.99E−02
2	261	2.15E−02	1.54E−02	1.67E−02	1.84E−02	2.08E−02	2.41E−02	2.69E−02	2.97E−02	5.09E−02
3 to <6	540	2.10E−02	1.63E−02	1.72E−02	1.87E−02	2.06E−02	2.29E−02	2.56E−02	2.71E−02	3.49E−02
6 to <11	940	2.23E−02	1.64E−02	1.72E−02	1.93E−02	2.16E−02	2.50E−02	2.76E−02	2.95E−02	4.34E−02
11 to <16	1,337	2.64E−02	1.93E−02	2.05E−02	2.26E−02	2.54E−02	2.92E−02	3.38E−02	3.69E−02	5.50E−02
16 to <21	1,241	2.90E−02	2.03E−02	2.17E−02	2.45E−02	2.80E−02	3.17E−02	3.82E−02	4.21E−02	6.74E−02
21 to <31	701	2.92E−02	1.97E−02	2.10E−02	2.42E−02	2.79E−02	3.30E−02	3.88E−02	4.31E−02	7.17E−02
31 to <41	728	3.03E−02	2.14E−02	2.27E−02	2.51E−02	2.91E−02	3.41E−02	3.96E−02	4.35E−02	5.77E−02
41 to <51	753	3.16E−02	2.26E−02	2.44E−02	2.72E−02	3.04E−02	3.51E−02	4.03E−02	4.50E−02	6.34E−02
51 to <61	627	3.27E−02	2.24E−02	2.40E−02	2.80E−02	3.14E−02	3.70E−02	4.17E−02	4.58E−02	7.05E−02
61 to <71	678	2.98E−02	2.25E−02	2.40E−02	2.61E−02	2.92E−02	3.23E−02	3.69E−02	4.00E−02	5.23E−02
71 to <81	496	2.93E−02	2.28E−02	2.39E−02	2.61E−02	2.88E−02	3.20E−02	3.57E−02	3.73E−02	4.49E−02
≥81	255	2.85E−02	2.25E−02	2.34E−02	2.55E−02	2.82E−02	3.10E−02	3.34E−02	3.55E−02	4.11E−02

Table 6-17. Descriptive Statistics for Average Ventilation Rate,[a] Unadjusted for Body Weight, While Performing Activities Within the Specified Activity Category, for Males by Age Category (continued)

Age Group (years)	N	Mean	Average Ventilation Rate (m^3/minute) Percentiles 5th	10th	25th	50th	75th	90th	95th	Maximum
High Intensity (METS >6.0)										
Birth to <1	183	2.75E−02	1.51E−02	1.73E−02	2.06E−02	2.78E−02	3.25E−02	3.84E−02	4.22E−02	5.79E−02
1	164	4.03E−02	2.83E−02	3.17E−02	3.47E−02	3.98E−02	4.43E−02	5.16E−02	5.59E−02	6.07E−02
2	162	4.05E−02	2.82E−02	2.97E−02	3.45E−02	4.06E−02	4.62E−02	5.19E−02	5.51E−02	9.20E−02
3 to <6	263	3.90E−02	2.95E−02	3.14E−02	3.40E−02	3.78E−02	4.32E−02	4.89E−02	5.22E−02	6.62E−02
6 to <11	637	4.36E−02	3.07E−02	3.28E−02	3.58E−02	4.19E−02	4.95E−02	5.66E−02	6.24E−02	8.99E−02
11 to <16	1,111	5.08E−02	3.43E−02	3.68E−02	4.15E−02	4.91E−02	5.74E−02	6.63E−02	7.29E−02	1.23E−01
16 to <21	968	5.32E−02	3.60E−02	3.83E−02	4.35E−02	5.05E−02	5.93E−02	7.15E−02	8.30E−02	1.30E−01
21 to <31	546	5.39E−02	3.36E−02	3.80E−02	4.48E−02	5.15E−02	6.16E−02	7.24E−02	8.21E−02	1.12E−01
31 to <41	567	5.43E−02	3.78E−02	4.04E−02	4.54E−02	5.21E−02	6.12E−02	7.14E−02	7.74E−02	1.04E−01
41 to <51	487	5.73E−02	3.83E−02	4.25E−02	4.83E−02	5.52E−02	6.45E−02	7.56E−02	8.44E−02	1.10E−01
51 to <61	452	5.84E−02	3.90E−02	4.16E−02	4.87E−02	5.59E−02	6.60E−02	7.86E−02	8.65E−02	1.41E−01
61 to <71	490	5.41E−02	3.63E−02	3.95E−02	4.52E−02	5.24E−02	6.08E−02	7.20E−02	7.52E−02	1.02E−01
71 to <81	343	5.25E−02	3.70E−02	3.95E−02	4.41E−02	5.00E−02	5.90E−02	6.76E−02	7.65E−02	9.73E−02
≥81	168	5.33E−02	3.54E−02	3.92E−02	4.55E−02	5.09E−02	6.12E−02	6.96E−02	7.71E−02	9.68E−02

[a] An individual's ventilation rate for the given activity category equals the weighted average of the individual's activity-specific ventilation rates for activities falling within the category, estimated using a multiple linear regression model, with weights corresponding to the number of minutes spent performing the activity. Numbers in these two columns represent averages, calculated across individuals in the specified age category, of these weighted averages. These are weighted averages, with the weights corresponding to the 4-year sampling weights assigned within NHANES 1999−2002.

N = Number of individuals.
MET = Metabolic equivalent.

Source: U.S. EPA (2009a).

Table 6-18. Descriptive Statistics for Average Ventilation Rate,[a] Adjusted for Body Weight, While Performing Activities Within the Specified Activity Category, for Males by Age Category

Age Group (years)	*N*	Mean	Average Ventilation Rate (m^3/minute-kg) Percentiles 5th	10th	25th	50th	75th	90th	95th	Maximum
Sleep or nap (Activity ID = 14500)										
Birth to <1	419	3.85E−04	2.81E−04	3.01E−04	3.37E−04	3.80E−04	4.27E−04	4.65E−04	5.03E−04	6.66E−04
1	308	3.95E−04	2.95E−04	3.13E−04	3.45E−04	3.84E−04	4.41E−04	4.91E−04	5.24E−04	6.26E−04
2	261	3.30E−04	2.48E−04	2.60E−04	2.89E−04	3.26E−04	3.62E−04	4.05E−04	4.42E−04	5.38E−04
3 to <6	540	2.43E−04	1.60E−04	1.74E−04	1.98E−04	2.37E−04	2.79E−04	3.14E−04	3.50E−04	4.84E−04
6 to <11	940	1.51E−04	1.02E−04	1.09E−04	1.25E−04	1.48E−04	1.74E−04	2.00E−04	2.15E−04	3.02E−04
11 to <16	1,337	9.80E−05	6.70E−05	7.20E−05	8.10E−05	9.40E−05	1.10E−04	1.29E−04	1.41E−04	2.08E−04
16 to <21	1,241	7.10E−05	4.70E−05	5.20E−05	6.10E−05	6.90E−05	8.00E−05	9.00E−05	9.80E−05	1.47E−04
21 to <31	701	5.80E−05	3.80E−05	4.20E−05	4.80E−05	5.60E−05	6.60E−05	7.60E−05	8.30E−05	1.32E−04
31 to <41	728	6.10E−05	3.80E−05	4.30E−05	5.00E−05	6.00E−05	7.00E−05	8.00E−05	8.60E−05	1.27E−04
41 to <51	753	6.50E−05	4.40E−05	4.70E−05	5.40E−05	6.40E−05	7.40E−05	8.60E−05	9.20E−05	1.37E−04
51 to <61	627	6.60E−05	4.50E−05	4.90E−05	5.50E−05	6.40E−05	7.60E−05	8.60E−05	9.30E−05	1.41E−04
61 to <71	678	6.90E−05	5.10E−05	5.40E−05	6.00E−05	6.80E−05	7.60E−05	8.60E−05	9.30E−05	1.17E−04
71 to <81	496	7.50E−05	5.50E−05	5.80E−05	6.40E−05	7.30E−05	8.30E−05	9.30E−05	9.90E−05	1.25E−04
≥81	255	8.00E−05	6.10E−05	6.40E−05	7.10E−05	7.80E−05	8.80E−05	9.70E−05	1.11E−04	1.22E−04
Sedentary and Passive Activities (METS ≤1.5—Includes Sleep or Nap)										
Birth to <1	419	3.97E−04	3.03E−04	3.17E−04	3.51E−04	3.91E−04	4.37E−04	4.70E−04	4.98E−04	6.57E−04
1	308	4.06E−04	3.21E−04	3.31E−04	3.63E−04	3.97E−04	4.48E−04	4.88E−04	5.25E−04	6.19E−04
2	261	3.43E−04	2.74E−04	2.86E−04	3.09E−04	3.40E−04	3.69E−04	4.05E−04	4.46E−04	5.10E−04
3 to <6	540	2.55E−04	1.78E−04	1.93E−04	2.15E−04	2.50E−04	2.88E−04	3.27E−04	3.46E−04	4.54E−04
6 to <11	940	1.60E−04	1.13E−04	1.18E−04	1.35E−04	1.57E−04	1.80E−04	2.09E−04	2.18E−04	2.89E−04
11 to <16	1,337	1.05E−04	7.70E−05	8.00E−05	8.80E−05	1.01E−04	1.18E−04	1.35E−04	1.42E−04	1.95E−04

Table 6-18. Descriptive Statistics for Average Ventilation Rate,[a] Adjusted for Body Weight, While Performing Activities Within the Specified Activity Category, for Males by Age Category (continued)

Age Group (years)	*N*	Mean	Average Ventilation Rate (m^3/minute-kg)							Maximum
			Percentiles							
			5th	10th	25th	50th	75th	90th	95th	
16 to <21	1,241	7.70E−05	5.50E−05	6.00E−05	6.80E−05	7.60E−05	8.50E−05	9.50E−05	1.02E−04	1.32E−04
21 to <31	701	6.20E−05	4.70E−05	4.90E−05	5.50E−05	6.10E−05	6.90E−05	7.70E−05	8.20E−05	1.18E−04
31 to <41	728	6.60E−05	4.60E−05	5.00E−05	5.70E−05	6.50E−05	7.40E−05	8.20E−05	8.60E−05	1.19E−04
41 to <51	753	7.10E−05	5.40E−05	5.70E−05	6.20E−05	7.00E−05	7.80E−05	8.60E−05	9.10E−05	1.29E−04
51 to <61	627	7.20E−05	5.50E−05	5.80E−05	6.30E−05	7.10E−05	7.90E−05	8.80E−05	9.20E−05	1.35E−04
61 to <71	678	7.60E−05	6.10E−05	6.40E−05	6.90E−05	7.50E−05	8.10E−05	8.90E−05	9.40E−05	1.11E−04
71 to <81	496	8.20E−05	6.70E−05	7.00E−05	7.50E−05	8.10E−05	8.80E−05	9.40E−05	9.80E−05	1.15E−04
≥81	255	8.60E−05	7.10E−05	7.50E−05	8.00E−05	8.60E−05	9.20E−05	9.90E−05	1.06E−04	1.15E−04
Light Intensity Activities (1.5< METS ≤3.0)										
Birth to <1	419	9.88E−04	7.86E−04	8.30E−04	8.97E−04	9.72E−04	1.07E−03	1.17E−03	1.20E−03	1.44E−03
1	308	1.02E−03	8.36E−04	8.59E−04	9.18E−04	1.01E−03	1.10E−03	1.22E−03	1.30E−03	1.49E−03
2	261	8.37E−04	6.83E−04	7.16E−04	7.61E−04	8.26E−04	8.87E−04	9.95E−04	1.03E−03	1.18E−03
3 to <6	540	6.33E−04	4.41E−04	4.80E−04	5.44E−04	6.26E−04	7.11E−04	7.94E−04	8.71E−04	1.08E−03
6 to <11	940	3.84E−04	2.67E−04	2.86E−04	3.24E−04	3.77E−04	4.37E−04	4.93E−04	5.29E−04	7.09E−04
11 to <16	1,337	2.46E−04	1.76E−04	1.87E−04	2.09E−04	2.38E−04	2.82E−04	3.11E−04	3.32E−04	4.42E−04
16 to <21	1,241	1.79E−04	1.37E−04	1.44E−04	1.56E−04	1.78E−04	1.99E−04	2.18E−04	2.30E−04	3.32E−04
21 to <31	701	1.58E−04	1.24E−04	1.30E−04	1.42E−04	1.54E−04	1.71E−04	1.90E−04	2.07E−04	2.90E−04
31 to <41	728	1.61E−04	1.18E−04	1.28E−04	1.40E−04	1.57E−04	1.77E−04	1.98E−04	2.09E−04	2.81E−04
41 to <51	753	1.66E−04	1.26E−04	1.33E−04	1.47E−04	1.64E−04	1.81E−04	2.00E−04	2.14E−04	3.32E−04
51 to <61	627	1.67E−04	1.27E−04	1.35E−04	1.48E−04	1.65E−04	1.83E−04	2.01E−04	2.16E−04	2.87E−04
61 to <71	678	1.64E−04	1.37E−04	1.41E−04	1.50E−04	1.63E−04	1.75E−04	1.87E−04	1.95E−04	2.69E−04
71 to <81	496	1.71E−04	1.43E−04	1.48E−04	1.58E−04	1.70E−04	1.82E−04	1.95E−04	2.03E−04	2.63E−04
≥81	255	1.85E−04	1.52E−04	1.60E−04	1.68E−04	1.83E−04	1.98E−04	2.12E−04	2.24E−04	2.47E−04

Table 6-18. Descriptive Statistics for Average Ventilation Rate,[a] Adjusted for Body Weight, While Performing Activities Within the Specified Activity Category, for Males by Age Category (continued)

Age Group (years)	*N*	Mean	Average Ventilation Rate (m^3/minute-kg) Percentiles 5th	10th	25th	50th	75th	90th	95th	Maximum
Moderate Intensity Activities (3.0< METS ≤6.0)										
Birth to <1	419	1.80E−03	1.40E−03	1.49E−03	1.62E−03	1.78E−03	1.94E−03	2.18E−03	2.28E−03	3.01E−03
1	308	1.88E−03	1.41E−03	1.50E−03	1.65E−03	1.82E−03	2.02E−03	2.34E−03	2.53E−03	3.23E−03
2	261	1.55E−03	1.21E−03	1.28E−03	1.40E−03	1.54E−03	1.66E−03	1.84E−03	2.02E−03	2.29E−03
3 to <6	540	1.17E−03	8.05E−04	8.83E−04	9.99E−04	1.12E−03	1.31E−03	1.56E−03	1.68E−03	2.10E−03
6 to <11	940	7.36E−04	5.03E−04	5.45E−04	6.18E−04	7.14E−04	8.34E−04	9.58E−04	1.04E−03	1.43E−03
11 to <16	1,337	4.91E−04	3.59E−04	3.75E−04	4.18E−04	4.73E−04	5.52E−04	6.35E−04	6.81E−04	1.06E−03
16 to <21	1,241	3.87E−04	2.81E−04	2.96E−04	3.34E−04	3.80E−04	4.31E−04	4.86E−04	5.18E−04	7.11E−04
21 to <31	701	3.57E−04	2.43E−04	2.64E−04	2.96E−04	3.45E−04	4.04E−04	4.68E−04	5.09E−04	8.24E−04
31 to <41	728	3.57E−04	2.42E−04	2.65E−04	3.00E−04	3.44E−04	4.00E−04	4.71E−04	5.21E−04	7.62E−04
41 to <51	753	3.66E−04	2.55E−04	2.72E−04	3.10E−04	3.53E−04	4.08E−04	4.69E−04	5.18E−04	7.16E−04
51 to <61	627	3.76E−04	2.59E−04	2.78E−04	3.13E−04	3.66E−04	4.31E−04	4.82E−04	5.49E−04	7.64E−04
61 to <71	678	3.44E−04	2.72E−04	2.84E−04	3.13E−04	3.42E−04	3.71E−04	3.99E−04	4.24E−04	5.73E−04
71 to <81	496	3.60E−04	2.91E−04	3.06E−04	3.28E−04	3.59E−04	3.88E−04	4.18E−04	4.36E−04	5.49E−04
≥81	255	3.83E−04	3.12E−04	3.23E−04	3.47E−04	3.77E−04	4.16E−04	4.47E−04	4.70E−04	5.29E−04

Table 6-18. Descriptive Statistics for Average Ventilation Rate,[a] Adjusted for Body Weight, While Performing Activities Within the Specified Activity Category, for Males by Age Category (continued)

Age Group (years)	*N*	Mean	Average Ventilation Rate (m^3/minute-kg)							Maximum
			Percentiles							
			5th	10th	25th	50th	75th	90th	95th	
High Intensity (METS >6.0)										
Birth to <1	183	3.48E−03	2.70E−03	2.93E−03	3.10E−03	3.46E−03	3.81E−03	4.14E−03	4.32E−03	5.08E−03
1	164	3.52E−03	2.52E−03	2.89E−03	3.22E−03	3.57E−03	3.91E−03	4.11E−03	4.34E−03	4.86E−03
2	162	2.89E−03	2.17E−03	2.34E−03	2.58E−03	2.87E−03	3.20E−03	3.43E−03	3.54E−03	4.30E−03
3 to <6	263	2.17E−03	1.55E−03	1.66E−03	1.81E−03	2.11E−03	2.50E−03	2.73E−03	2.98E−03	3.62E−03
6 to <11	637	1.41E−03	9.36E−04	1.03E−03	1.19E−03	1.38E−03	1.59E−03	1.83E−03	1.93E−03	2.68E−03
11 to <16	1,111	9.50E−04	6.35E−04	6.96E−04	7.90E−04	9.09E−04	1.09E−03	1.27E−03	1.36E−03	1.98E−03
16 to <21	968	7.11E−04	4.75E−04	5.27E−04	5.99E−04	6.91E−04	8.02E−04	9.17E−04	9.97E−04	1.94E−03
21 to <31	546	6.60E−04	4.49E−04	4.74E−04	5.43E−04	6.44E−04	7.49E−04	8.55E−04	9.73E−04	1.27E−03
31 to <41	567	6.44E−04	4.42E−04	4.70E−04	5.33E−04	6.25E−04	7.31E−04	8.53E−04	9.30E−04	1.23E−03
41 to <51	487	6.55E−04	4.38E−04	4.85E−04	5.48E−04	6.25E−04	7.41E−04	8.56E−04	9.44E−04	1.77E−03
51 to <61	452	6.75E−04	4.46E−04	4.81E−04	5.47E−04	6.43E−04	7.67E−04	9.13E−04	1.02E−03	1.32E−03
61 to <71	490	6.24E−04	4.41E−04	4.70E−04	5.31E−04	6.12E−04	7.03E−04	7.88E−04	8.55E−04	1.08E−03
71 to <81	343	6.46E−04	4.66E−04	5.02E−04	5.53E−04	6.26E−04	7.16E−04	8.49E−04	9.10E−04	1.04E−03
≥81	168	7.16E−04	5.05E−04	5.44E−04	6.02E−04	7.00E−04	8.05E−04	9.42E−04	9.91E−04	1.35E−03

[a] An individual's ventilation rate for the given activity category equals the weighted average of the individual's activity-specific ventilation rates for activities falling within the category, estimated using a multiple linear regression model, with weights corresponding to the number of minutes spent performing the activity. Numbers in these two columns represent averages, calculated across individuals in the specified age category, of these weighted averages. These are weighted averages, with the weights corresponding to the 4-year sampling weights assigned within NHANES 1999−2002.

N = Number of individuals.
MET = Metabolic equivalent.

Source: U.S. EPA (2009a).

Table 6-19. Descriptive Statistics for Average Ventilation Rate,[a] Unadjusted for Body Weight, While Performing Activities Within the Specified Activity Category, for Females by Age Category

Age Group (years)	*N*	Mean	Average Ventilation Rate (m^3/minute)							
			Percentiles							Maximum
			5th	10th	25th	50th	75th	90th	95th	
Sleep or nap (Activity ID = 14500)										
Birth to <1	415	2.92E−03	1.54E−03	1.72E−03	2.27E−03	2.88E−03	3.50E−03	4.04E−03	4.40E−03	8.69E−03
1	245	4.59E−03	3.02E−03	3.28E−03	3.76E−03	4.56E−03	5.32E−03	5.96E−03	6.37E−03	9.59E−03
2	255	4.56E−03	3.00E−03	3.30E−03	3.97E−03	4.52E−03	5.21E−03	5.76E−03	6.15E−03	9.48E−03
3 to <6	543	4.18E−03	2.90E−03	3.20E−03	3.62E−03	4.10E−03	4.71E−03	5.22E−03	5.73E−03	7.38E−03
6 to <11	894	4.36E−03	2.97E−03	3.17E−03	3.69E−03	4.24E−03	4.93E−03	5.67E−03	6.08E−03	8.42E−03
11 to <16	1,451	4.81E−03	3.34E−03	3.57E−03	3.99E−03	4.66E−03	5.39E−03	6.39E−03	6.99E−03	9.39E−03
16 to <21	1,182	4.40E−03	2.78E−03	2.96E−03	3.58E−03	4.26E−03	5.05E−03	5.89E−03	6.63E−03	1.23E−02
21 to <31	1,023	3.89E−03	2.54E−03	2.74E−03	3.13E−03	3.68E−03	4.44E−03	5.36E−03	6.01E−03	9.58E−03
31 to <41	869	4.00E−03	2.66E−03	2.86E−03	3.31E−03	3.89E−03	4.54E−03	5.28E−03	5.77E−03	8.10E−03
41 to <51	763	4.40E−03	3.00E−03	3.23E−03	3.69E−03	4.25E−03	4.95E−03	5.66E−03	6.25E−03	8.97E−03
51 to <61	622	4.56E−03	3.12E−03	3.30E−03	3.72E−03	4.41E−03	5.19E−03	6.07E−03	6.63E−03	8.96E−03
61 to <71	700	4.47E−03	3.22E−03	3.35E−03	3.78E−03	4.38E−03	4.99E−03	5.72E−03	6.37E−03	9.57E−03
71 to <81	470	4.52E−03	3.31E−03	3.47E−03	3.89E−03	4.40E−03	5.11E−03	5.67E−03	6.06E−03	7.35E−03
≥81	306	4.49E−03	3.17E−03	3.49E−03	3.82E−03	4.39E−03	4.91E−03	5.61E−03	6.16E−03	8.27E−03
Sedentary and Passive Activities (METS ≤1.5—Includes Sleep or Nap)										
Birth to <1	415	3.00E−03	1.60E−03	1.80E−03	2.32E−03	2.97E−03	3.58E−03	4.11E−03	4.44E−03	9.59E−03
1	245	4.71E−03	3.26E−03	3.44E−03	3.98E−03	4.73E−03	5.30E−03	5.95E−03	6.63E−03	9.50E−03
2	255	4.73E−03	3.34E−03	3.53E−03	4.19E−03	4.67E−03	5.25E−03	5.75E−03	6.22E−03	9.42E−03
3 to <6	543	4.40E−03	3.31E−03	3.49E−03	3.95E−03	4.34E−03	4.84E−03	5.29E−03	5.73E−03	7.08E−03
6 to <11	894	4.64E−03	3.41E−03	3.67E−03	4.04E−03	4.51E−03	5.06E−03	5.88E−03	6.28E−03	8.31E−03
11 to <16	1,451	5.21E−03	3.90E−03	4.16E−03	4.53E−03	5.09E−03	5.68E−03	6.53E−03	7.06E−03	9.07E−03

Table 6-19. Descriptive Statistics for Average Ventilation Rate,[a] Unadjusted for Body Weight, While Performing Activities Within the Specified Activity Category, for Females by Age Category (continued)

Age Group (years)	*N*	Mean	Average Ventilation Rate (m^3/minute)							Maximum
			Percentiles							
			5th	10th	25th	50th	75th	90th	95th	
16 to <21	1,182	4.76E−03	3.26E−03	3.56E−03	4.03E−03	4.69E−03	5.32E−03	6.05E−03	6.60E−03	1.18E−02
21 to <31	1,023	4.19E−03	3.04E−03	3.19E−03	3.55E−03	4.00E−03	4.63E−03	5.38E−03	6.02E−03	9.22E−03
31 to <41	869	4.33E−03	3.22E−03	3.45E−03	3.77E−03	4.24E−03	4.80E−03	5.33E−03	5.79E−03	7.70E−03
41 to <51	763	4.75E−03	3.60E−03	3.82E−03	4.18E−03	4.65E−03	5.19E−03	5.74E−03	6.26E−03	8.70E−03
51 to <61	622	4.96E−03	3.78E−03	4.00E−03	4.36E−03	4.87E−03	5.44E−03	6.06E−03	6.44E−03	8.30E−03
61 to <71	700	4.89E−03	3.81E−03	4.02E−03	4.34E−03	4.81E−03	5.30E−03	5.86E−03	6.29E−03	8.18E−03
71 to <81	470	4.95E−03	4.07E−03	4.13E−03	4.41E−03	4.89E−03	5.42E−03	5.89E−03	6.15E−03	7.59E−03
≥81	306	4.89E−03	3.93E−03	4.10E−03	4.39E−03	4.79E−03	5.25E−03	5.71E−03	6.12E−03	7.46E−03
Light Intensity Activities (1.5< METS ≤3.0)										
Birth to <1	415	7.32E−03	3.79E−03	4.63E−03	5.73E−03	7.19E−03	8.73E−03	9.82E−03	1.08E−02	1.70E−02
1	245	1.16E−02	8.59E−03	8.80E−03	1.00E−02	1.12E−02	1.29E−02	1.52E−02	1.58E−02	2.02E−02
2	255	1.20E−02	8.74E−03	9.40E−03	1.03E−02	1.17E−02	1.32E−02	1.56E−02	1.63E−02	2.36E−02
3 to <6	543	1.09E−02	8.83E−03	9.04E−03	9.87E−03	1.07E−02	1.17E−02	1.29E−02	1.38E−02	1.64E−02
6 to <11	894	1.11E−02	8.51E−03	9.02E−03	9.79E−03	1.08E−02	1.20E−02	1.35E−02	1.47E−02	2.22E−02
11 to <16	1,451	1.20E−02	9.40E−03	9.73E−03	1.06E−02	1.18E−02	1.31E−02	1.47E−02	1.58E−02	2.21E−02
16 to <21	1,182	1.11E−02	8.31E−03	8.73E−03	9.64E−03	1.08E−02	1.23E−02	1.38E−02	1.49E−02	2.14E−02
21 to <31	1,023	1.06E−02	7.75E−03	8.24E−03	9.05E−03	1.02E−02	1.17E−02	1.34E−02	1.43E−02	2.15E−02
31 to <41	869	1.11E−02	8.84E−03	9.30E−03	9.96E−03	1.09E−02	1.19E−02	1.31E−02	1.39E−02	1.74E−02
41 to <51	763	1.18E−02	9.64E−03	1.00E−02	1.07E−02	1.16E−02	1.27E−02	1.39E−02	1.45E−02	1.77E−02
51 to <61	622	1.20E−02	9.76E−03	1.02E−02	1.09E−02	1.18E−02	1.30E−02	1.42E−02	1.49E−02	1.79E−02
61 to <71	700	1.08E−02	8.87E−03	9.28E−03	9.85E−03	1.06E−02	1.17E−02	1.26E−02	1.32E−02	1.74E−02
71 to <81	470	1.08E−02	8.84E−03	9.23E−03	9.94E−03	1.07E−02	1.17E−02	1.25E−02	1.30E−02	1.76E−02

Table 6-19. Descriptive Statistics for Average Ventilation Rate,[a] Unadjusted for Body Weight, While Performing Activities Within the Specified Activity Category, for Females by Age Category (continued)

Age Group (years)	N	Mean	Average Ventilation Rate (m^3/minute) Percentiles 5th	10th	25th	50th	75th	90th	95th	Maximum
≥81	306	1.04E−02	8.69E−03	8.84E−03	9.36E−03	1.03E−02	1.14E−02	1.21E−02	1.26E−02	1.61E−02
Moderate Intensity Activities (3.0< METS ≤6.0)										
Birth to <1	415	1.40E−02	7.91E−03	9.00E−03	1.12E−02	1.35E−02	1.63E−02	1.94E−02	2.23E−02	4.09E−02
1	245	2.10E−02	1.56E−02	1.63E−02	1.79E−02	2.01E−02	2.35E−02	2.71E−02	2.93E−02	3.45E−02
2	255	2.13E−02	1.42E−02	1.56E−02	1.82E−02	2.15E−02	2.39E−02	2.76E−02	2.88E−02	3.76E−02
3 to <6	543	2.00E−02	1.53E−02	1.63E−02	1.78E−02	1.98E−02	2.16E−02	2.38E−02	2.59E−02	3.29E−02
6 to <11	894	2.10E−02	1.60E−02	1.68E−02	1.85E−02	2.04E−02	2.30E−02	2.61E−02	2.81E−02	4.31E−02
11 to <16	1,451	2.36E−02	1.82E−02	1.95E−02	2.08E−02	2.30E−02	2.54E−02	2.84E−02	3.14E−02	4.24E−02
16 to <21	1,182	2.32E−02	1.66E−02	1.76E−02	1.96E−02	2.24E−02	2.61E−02	3.03E−02	3.20E−02	5.25E−02
21 to <31	1,023	2.29E−02	1.56E−02	1.67E−02	1.90E−02	2.19E−02	2.60E−02	3.00E−02	3.28E−02	5.42E−02
31 to <41	869	2.27E−02	1.69E−02	1.76E−02	1.95E−02	2.20E−02	2.48E−02	2.89E−02	3.11E−02	4.73E−02
41 to <51	763	2.45E−02	1.76E−02	1.89E−02	2.08E−02	2.39E−02	2.74E−02	3.08E−02	3.36E−02	5.07E−02
51 to <61	622	2.52E−02	1.88E−02	1.98E−02	2.18E−02	2.43E−02	2.81E−02	3.19E−02	3.50E−02	4.62E−02
61 to <71	700	2.14E−02	1.69E−02	1.77E−02	1.92E−02	2.09E−02	2.32E−02	2.57E−02	2.73E−02	3.55E−02
71 to <81	470	2.11E−02	1.69E−02	1.76E−02	1.89E−02	2.07E−02	2.29E−02	2.49E−02	2.64E−02	3.44E−02
≥81	306	2.09E−02	1.65E−02	1.75E−02	1.91E−02	2.06E−02	2.25E−02	2.46E−02	2.60E−02	2.93E−02

Table 6-19. Descriptive Statistics for Average Ventilation Rate,[a] Unadjusted for Body Weight, While Performing Activities Within the Specified Activity Category, for Females by Age Category (continued)

Age Group (years)	N	Mean	Average Ventilation Rate (m^3/minute) Percentiles 5th	10th	25th	50th	75th	90th	95th	Maximum
High Intensity (METS >6.0)										
Birth to <1	79	2.42E−02	1.24E−02	1.33E−02	1.72E−02	2.25E−02	2.93E−02	3.56E−02	4.07E−02	7.46E−02
1	55	3.65E−02	2.59E−02	2.62E−02	3.04E−02	3.61E−02	4.20E−02	4.73E−02	4.86E−02	7.70E−02
2	130	3.76E−02	2.90E−02	3.05E−02	3.23E−02	3.64E−02	4.08E−02	4.81E−02	5.14E−02	7.30E−02
3 to <6	347	3.45E−02	2.70E−02	2.82E−02	3.00E−02	3.33E−02	3.76E−02	4.32E−02	4.47E−02	5.66E−02
6 to <11	707	3.94E−02	2.86E−02	3.01E−02	3.37E−02	3.80E−02	4.41E−02	5.05E−02	5.46E−02	8.29E−02
11 to <16	1,170	4.66E−02	3.11E−02	3.38E−02	3.88E−02	4.53E−02	5.29E−02	6.08E−02	6.63E−02	1.02E−01
16 to <21	887	4.41E−02	2.87E−02	3.06E−02	3.65E−02	4.27E−02	5.02E−02	5.82E−02	6.34E−02	1.09E−01
21 to <31	796	4.57E−02	2.88E−02	3.12E−02	3.67E−02	4.31E−02	5.22E−02	6.19E−02	6.89E−02	1.08E−01
31 to <41	687	4.44E−02	3.03E−02	3.29E−02	3.70E−02	4.22E−02	5.05E−02	5.95E−02	6.53E−02	8.95E−02
41 to <51	515	4.70E−02	3.10E−02	3.40E−02	3.84E−02	4.56E−02	5.41E−02	6.15E−02	6.74E−02	8.87E−02
51 to <61	424	4.74E−02	3.15E−02	3.48E−02	3.94E−02	4.57E−02	5.41E−02	6.23E−02	6.88E−02	8.44E−02
61 to <71	465	4.00E−02	2.76E−02	3.06E−02	3.46E−02	3.87E−02	4.53E−02	5.08E−02	5.64E−02	7.13E−02
71 to <81	304	4.06E−02	2.85E−02	3.01E−02	3.43E−02	3.96E−02	4.70E−02	5.20E−02	5.41E−02	7.53E−02
≥81	188	4.19E−02	2.85E−02	3.09E−03	3.44E−02	4.14E−02	4.76E−02	5.56E−02	5.83E−02	7.21E−02

[a] An individual's ventilation rate for the given activity category equals the weighted average of the individual's activity-specific ventilation rates for activities falling within the category, estimated using a multiple linear regression model, with weights corresponding to the number of minutes spent performing the activity. Numbers in these two columns represent averages, calculated across individuals in the specified age category, of these weighted averages. These are weighted averages, with the weights corresponding to the 4-year sampling weights assigned within NHANES 1999−2002.

N = Number of individuals.
MET = Metabolic equivalent.

Source: U.S. EPA (2009a).

Table 6-20. Descriptive Statistics for Average Ventilation Rate,[a] Adjusted for Body Weight, While Performing Activities Within the Specified Activity Category, for Females by Age Category

Age Group (years)	*N*	Mean	Average Ventilation Rate (m^3/minute-kg)							
			Percentiles							
			5th	10th	25th	50th	75th	90th	95th	Maximum
Sleep or nap (Activity ID = 14500)										
Birth to <1	415	3.91E−04	2.80E−04	3.01E−04	3.35E−04	3.86E−04	4.34E−04	4.79E−04	5.17E−04	7.39E−04
1	245	4.14E−04	3.15E−04	3.29E−04	3.61E−04	4.05E−04	4.64E−04	5.21E−04	5.36E−04	6.61E−04
2	255	3.42E−04	2.58E−04	2.71E−04	2.93E−04	3.33E−04	3.91E−04	4.25E−04	4.53E−04	4.94E−04
3 to <6	543	2.38E−04	1.45E−04	1.63E−04	1.95E−04	2.33E−04	2.75E−04	3.20E−04	3.53E−04	5.19E−04
6 to <11	894	1.51E−04	8.90E−05	9.70E−05	1.20E−04	1.46E−04	1.76E−04	2.11E−04	2.29E−04	2.97E−04
11 to <16	1,451	9.00E−05	5.90E−05	6.50E−05	7.50E−05	8.70E−05	1.02E−04	1.18E−04	1.30E−04	1.76E−04
16 to <21	1,182	6.90E−05	4.40E−05	4.70E−05	5.70E−05	6.70E−05	8.00E−05	9.30E−05	1.02E−04	1.52E−04
21 to <31	1,023	5.50E−05	3.50E−05	3.80E−05	4.50E−05	5.40E−05	6.50E−05	7.40E−05	8.20E−05	9.80E−05
31 to <41	869	5.60E−05	3.40E−05	3.70E−05	4.50E−05	5.40E−05	6.50E−05	7.60E−05	8.20E−05	1.15E−04
41 to <51	763	6.00E−05	3.90E−05	4.10E−05	4.80E−05	5.70E−05	7.00E−05	8.40E−05	9.00E−05	1.14E−04
51 to <61	622	6.10E−05	3.90E−05	4.20E−05	5.00E−05	5.90E−05	7.10E−05	8.30E−05	8.80E−05	1.35E−04
61 to <71	700	6.10E−05	4.30E−05	4.60E−05	5.20E−05	5.90E−05	6.70E−05	7.60E−05	8.10E−05	1.01E−04
71 to <81	470	6.60E−05	4.70E−05	5.10E−05	5.60E−05	6.40E−05	7.40E−05	8.40E−05	9.00E−05	1.25E−04
≥81	306	7.20E−05	5.10E−05	5.60E−05	6.30E−05	7.00E−05	7.90E−05	9.10E−05	9.60E−05	1.15E−04
Sedentary and Passive Activities (METS ≤1.5—Includes Sleep or Nap)										
Birth to <1	415	4.02E−04	2.97E−04	3.16E−04	3.52E−04	3.96E−04	4.46E−04	4.82E−04	5.19E−04	7.19E−04
1	245	4.25E−04	3.35E−04	3.48E−04	3.76E−04	4.18E−04	4.69E−04	5.12E−04	5.43E−04	6.42E−04
2	255	3.55E−04	2.85E−04	2.96E−04	3.20E−04	3.48E−04	3.91E−04	4.20E−04	4.42E−04	4.85E−04
3 to <6	543	2.51E−04	1.64E−04	1.79E−04	2.11E−04	2.48E−04	2.84E−04	3.28E−04	3.58E−04	4.89E−04
6 to <11	894	1.60E−04	9.90E−05	1.10E−04	1.31E−04	1.57E−04	1.85E−04	2.12E−04	2.34E−04	2.93E−04
11 to <16	1,451	9.70E−05	7.10E−05	7.50E−05	8.30E−05	9.50E−05	1.09E−04	1.23E−04	1.33E−04	1.74E−04

Table 6-20. Descriptive Statistics for Average Ventilation Rate,[a] Adjusted for Body Weight, While Performing Activities Within the Specified Activity Category, for Females by Age Category (continued)

Age Group (years)	*N*	Mean	Average Ventilation Rate (m^3/minute-kg) Percentiles 5th	10th	25th	50th	75th	90th	95th	Maximum
16 to <21	1,182	7.50E−05	5.30E−05	5.70E−05	6.30E−05	7.40E−05	8.50E−05	9.60E−05	1.04E−04	1.41E−04
21 to <31	1,023	6.00E−05	4.30E−05	4.50E−05	5.10E−05	5.90E−05	6.70E−05	7.50E−05	8.00E−05	9.90E−05
31 to <41	869	6.00E−05	4.00E−05	4.20E−05	5.10E−05	5.90E−05	6.90E−05	7.80E−05	8.30E−05	1.05E−04
41 to <51	763	6.50E−05	4.40E−05	4.80E−05	5.50E−05	6.30E−05	7.30E−05	8.30E−05	9.10E−05	1.14E−04
51 to <61	622	6.70E−05	4.60E−05	5.10E−05	5.70E−05	6.50E−05	7.60E−05	8.30E−05	9.00E−05	1.18E−04
61 to <71	700	6.60E−05	5.20E−05	5.40E−05	5.90E−05	6.60E−05	7.20E−05	7.80E−05	8.40E−05	1.04E−04
71 to <81	470	7.20E−05	5.50E−05	6.00E−05	6.50E−05	7.10E−05	7.80E−05	8.80E−05	9.20E−05	1.48E−04
≥81	306	7.80E−05	6.30E−05	6.50E−05	7.00E−05	7.70E−05	8.60E−05	9.30E−05	9.60E−05	1.12E−04
Light Intensity Activities (1.5< METS ≤3.0)										
Birth to <1	415	9.78E−04	7.91E−04	8.17E−04	8.80E−04	9.62E−04	1.05E−03	1.18E−03	1.23E−03	1.65E−03
1	245	1.05E−03	8.45E−04	8.68E−04	9.49E−04	1.04E−03	1.14E−03	1.25E−03	1.27E−03	1.64E−03
2	255	8.97E−04	7.30E−04	7.63E−04	8.19E−04	8.93E−04	9.64E−04	1.04E−03	1.10E−03	1.26E−03
3 to <6	543	6.19E−04	4.48E−04	4.84E−04	5.37E−04	5.99E−04	6.98E−04	7.83E−04	8.28E−04	1.02E−03
6 to <11	894	3.82E−04	2.52E−04	2.70E−04	3.15E−04	3.76E−04	4.42E−04	5.03E−04	5.39E−04	7.10E−04
11 to <16	1,451	2.25E−04	1.63E−04	1.74E−04	1.96E−04	2.17E−04	2.49E−04	2.84E−04	3.05E−04	3.96E−04
16 to <21	1,182	1.74E−04	1.29E−04	1.38E−04	1.54E−04	1.73E−04	1.93E−04	2.13E−04	2.24E−04	2.86E−04
21 to <31	1,023	1.49E−04	1.16E−04	1.23E−04	1.34E−04	1.49E−04	1.63E−04	1.78E−04	1.90E−04	2.27E−04
31 to <41	869	1.54E−04	1.07E−04	1.15E−04	1.33E−04	1.54E−04	1.76E−04	1.92E−04	2.02E−04	2.67E−04
41 to <51	763	1.61E−04	1.14E−04	1.23E−04	1.38E−04	1.58E−04	1.82E−04	2.03E−04	2.16E−04	2.83E−04
51 to <61	622	1.61E−04	1.20E−04	1.27E−04	1.41E−04	1.58E−04	1.80E−04	1.99E−04	2.10E−04	2.65E−04
61 to <71	700	1.47E−04	1.17E−04	1.22E−04	1.32E−04	1.45E−04	1.61E−04	1.73E−04	1.82E−04	2.44E−04
71 to <81	470	1.58E−04	1.24E−04	1.30E−04	1.43E−04	1.56E−04	1.69E−04	1.88E−04	2.02E−04	2.77E−04
≥81	306	1.67E−04	1.31E−04	1.38E−04	1.50E−04	1.64E−04	1.82E−04	1.97E−04	2.08E−04	2.34E−04

Table 6-20. Descriptive Statistics for Average Ventilation Rate,[a] Adjusted for Body Weight, While Performing Activities Within the Specified Activity Category, for Females by Age Category (continued)

Age Group (years)	*N*	Mean	Average Ventilation Rate (m^3/minute-kg)							Maximum
			Percentiles							
			5^{th}	10^{th}	25^{th}	50^{th}	75^{th}	90^{th}	95^{th}	
Moderate Intensity Activities (3.0< METS ≤6.0)										
Birth to <1	415	1.87E−03	1.47E−03	1.52E−03	1.67E−03	1.85E−03	2.01E−03	2.25E−03	2.40E−03	2.83E−03
1	245	1.90E−03	1.52E−03	1.62E−03	1.73E−03	1.87E−03	2.02E−03	2.24E−03	2.37E−03	3.24E−03
2	255	1.60E−03	1.27E−03	1.31E−03	1.44E−03	1.58E−03	1.75E−03	1.92E−03	2.02E−03	2.59E−03
3 to <6	543	1.14E−03	7.92E−04	8.53E−04	9.64E−04	1.11E−03	1.31E−03	1.45E−03	1.56E−03	1.93E−03
6 to <11	894	7.23E−04	4.62E−04	5.12E−04	5.98E−04	7.15E−04	8.38E−04	9.42E−04	1.01E−03	1.37E−03
11 to <16	1,451	4.41E−04	3.17E−04	3.38E−04	3.80E−04	4.31E−04	4.92E−04	5.51E−04	6.11E−04	9.86E−04
16 to <21	1,182	3.65E−04	2.67E−04	2.82E−04	3.10E−04	3.51E−04	4.07E−04	4.63E−04	4.94E−04	6.50E−04
21 to <31	1,023	3.25E−04	2.35E−04	2.45E−04	2.81E−04	3.16E−04	3.60E−04	4.16E−04	4.52E−04	6.57E−04
31 to <41	869	3.16E−04	2.13E−04	2.31E−04	2.68E−04	3.04E−04	3.50E−04	4.10E−04	4.60E−04	7.08E−04
41 to <51	763	3.33E−04	2.21E−04	2.36E−04	2.76E−04	3.25E−04	3.76E−04	4.41E−04	4.88E−04	6.20E−04
51 to <61	622	3.39E−04	2.35E−04	2.54E−04	2.83E−04	3.26E−04	3.83E−04	4.38E−04	4.86E−04	3.69E−04
61 to <71	700	2.92E−04	2.24E−04	2.38E−04	2.59E−04	2.85E−04	3.20E−04	3.51E−04	3.71E−04	5.11E−04
71 to <81	470	3.08E−04	2.40E−04	2.50E−04	2.70E−04	2.99E−04	3.40E−04	3.75E−04	4.07E−04	6.77E−04
≥81	306	3.35E−04	2.47E−04	2.66E−04	2.98E−04	3.33E−04	3.72E−04	4.02E−04	4.20E−04	5.20E−04

Table 6-20. Descriptive Statistics for Average Ventilation Rate,[a] Adjusted for Body Weight, While Performing Activities Within the Specified Activity Category, for Females by Age Category (continued)

Age Group (years)	N	Mean	Average Ventilation Rate (m^3/minute-kg)							Maximum
			Percentiles							
			5th	10th	25th	50th	75th	90th	95th	
High Intensity (METS >6.0)										
Birth to <1	79	3.26E−03	2.53E−03	2.62E−03	2.89E−03	3.23E−03	3.63E−03	3.96E−03	4.08E−03	5.02E−03
1	55	3.38E−03	2.57E−03	2.75E−03	2.97E−03	3.24E−03	3.71E−03	4.16E−03	4.87E−03	4.88E−03
2	130	2.80E−03	2.20E−03	2.31E−03	2.48E−03	2.81E−03	3.13E−03	3.36E−03	3.48E−03	3.88E−03
3 to <6	347	1.98E−03	1.36E−03	1.51E−03	1.69E−03	1.90E−03	2.19E−03	2.50E−03	2.99E−03	3.24E−03
6 to <11	707	1.33E−03	8.85E−04	9.67E−04	1.12E−03	1.33E−03	1.52E−03	1.72E−03	1.81E−03	2.22E−03
11 to <16	1,170	8.79E−04	5.89E−04	6.25E−04	7.12E−04	8.53E−04	1.01E−03	1.18E−03	1.31E−03	2.05E−03
16 to <21	887	6.96E−04	4.52E−04	4.96E−04	5.67E−04	6.86E−04	7.93E−04	9.16E−04	1.00E−03	1.50E−03
21 to <31	796	6.50E−04	4.17E−04	4.62E−04	5.46E−04	6.27E−04	7.30E−04	8.84E−04	9.39E−04	1.30E−03
31 to <41	687	6.13E−04	3.84E−04	4.20E−04	4.96E−04	5.90E−04	7.08E−04	8.35E−04	9.05E−04	1.55E−03
41 to <51	515	6.35E−04	3.79E−04	4.44E−04	5.17E−04	6.41E−04	7.65E−04	8.79E−04	9.50E−04	1.61E−03
51 to <61	424	6.34E−04	3.93E−04	4.31E−04	5.07E−04	6.12E−04	7.55E−04	8.51E−04	9.28E−04	1.37E−03
61 to <71	465	5.44E−04	3.64E−04	4.04E−04	4.49E−04	5.29E−04	6.10E−04	7.18E−04	8.03E−04	1.11E−03
71 to <81	304	5.94E−04	3.95E−04	4.45E−04	4.98E−04	5.80E−04	6.75E−04	7.76E−04	8.29E−04	1.26E−03
≥81	188	6.66E−04	4.54E−04	4.80E−04	5.43E−04	6.26E−04	7.68E−04	9.32E−04	9.72E−04	1.22E−03

[a] An individual's ventilation rate for the given activity category equals the weighted average of the individual's activity-specific ventilation rates for activities falling within the category, estimated using a multiple linear regression model, with weights corresponding to the number of minutes spent performing the activity. Numbers in these two columns represent averages, calculated across individuals in the specified age category, of these weighted averages. These are weighted averages, with the weights corresponding to the 4-year sampling weights assigned within NHANES 1999−2002.

N = Number of individuals.
MET = Metabolic equivalent.

Source: U.S. EPA (2009a).

Table 6-21. Descriptive Statistics for Duration of Time (hours/day) Spent Performing Activities Within the Specified Activity Category, by Age for Males[a]

Age Group (years)	*N*	Mean	Duration (hours/day) Spent at Activity — Percentiles 5th	10th	25th	50th	75th	90th	95th	Maximum
Sleep or nap (Activity ID = 14500)										
Birth to <1	419	13.51	12.63	12.78	13.19	13.53	13.88	14.24	14.46	15.03
1	308	12.61	11.89	12.15	12.34	12.61	12.89	13.13	13.29	13.79
2	261	12.06	11.19	11.45	11.80	12.07	12.39	12.65	12.75	13.40
3 to <6	540	11.18	10.57	10.70	10.94	11.18	11.45	11.63	11.82	12.39
6 to <11	940	10.18	9.65	9.75	9.93	10.19	10.39	10.59	10.72	11.24
11 to <16	1,337	9.38	8.84	8.94	9.15	9.38	9.61	9.83	9.95	10.33
16 to <21	1,241	8.69	7.91	8.08	8.36	8.67	9.03	9.34	9.50	10.44
21 to <31	701	8.36	7.54	7.70	8.02	8.36	8.67	9.03	9.23	9.77
31 to <41	728	8.06	7.36	7.50	7.77	8.06	8.36	8.59	8.76	9.82
41 to <51	753	7.89	7.15	7.30	7.58	7.88	8.17	8.48	8.68	9.38
51 to <61	627	7.96	7.29	7.51	7.69	7.96	8.23	8.48	8.66	9.04
61 to <71	678	8.31	7.65	7.78	8.01	8.30	8.6	8.83	9.01	9.66
71 to <81	496	8.51	7.80	8.02	8.27	8.53	8.74	8.99	9.10	9.89
≥81	255	9.24	8.48	8.64	8.97	9.25	9.54	9.74	9.96	10.69
Sedentary and Passive Activities (METS ≤1.5—Includes Sleep or Nap)										
Birth to <1	419	14.95	13.82	14.03	14.49	14.88	15.44	15.90	16.12	17.48
1	308	14.27	13.22	13.33	13.76	14.25	14.74	15.08	15.38	16.45
2	261	14.62	13.52	13.67	14.11	14.54	15.11	15.60	15.77	17.28
3 to <6	540	14.12	13.01	13.18	13.54	14.03	14.53	15.26	15.62	17.29
6 to <11	940	13.51	12.19	12.45	12.86	13.30	13.85	14.82	15.94	19.21
11 to <16	1,337	13.85	12.39	12.65	13.06	13.61	14.30	15.41	16.76	18.79
16 to <21	1,241	13.21	11.39	11.72	12.32	13.08	13.97	14.83	15.44	18.70
21 to <31	701	12.41	10.69	11.06	11.74	12.39	13.09	13.75	14.16	15.35
31 to <41	728	12.31	10.73	10.98	11.61	12.24	12.98	13.63	14.05	15.58
41 to <51	753	12.32	10.56	11.00	11.67	12.30	12.95	13.67	13.98	15.48
51 to <61	627	13.06	11.47	11.86	12.36	13.03	13.72	14.38	14.76	15.95
61 to <71	678	14.49	12.96	13.24	13.76	14.48	15.16	15.72	16.24	17.50
71 to <81	496	15.90	14.22	14.67	15.25	15.94	16.65	17.11	17.46	18.47
≥81	255	16.58	15.13	15.45	15.92	16.64	17.21	17.7	18.06	18.76

Table 6-21. Descriptive Statistics for Duration of Time (hours/day) Spent Performing Activities Within the Specified Activity Category, by Age for Males[a] (continued)

Age Group (years)	*N*	Mean	Duration (hours/day) Spent at Activity — Percentiles 5th	10th	25th	50th	75th	90th	95th	Maximum
Light Intensity Activities (1.5< METS ≤3.0)										
Birth to <1	419	5.30	2.97	3.25	3.71	4.52	7.29	8.08	8.50	9.91
1	308	5.52	2.68	2.89	3.37	4.31	8.23	9.04	9.73	10.90
2	261	5.48	3.06	3.26	3.85	4.58	7.58	8.83	9.04	9.92
3 to <6	540	6.60	3.86	4.25	5.16	6.20	8.26	9.31	9.70	10.74
6 to <11	940	7.62	5.07	5.57	6.63	7.63	8.72	9.78	10.12	11.59
11 to <16	1,337	7.50	4.48	5.59	6.75	7.67	8.51	9.19	9.63	10.91
16 to <21	1,241	7.13	4.37	4.97	6.00	7.02	8.29	9.43	10.03	11.50
21 to <31	701	6.09	3.15	3.50	4.20	5.08	8.49	9.96	10.47	12.25
31 to <41	728	5.72	2.80	3.12	3.70	4.64	8.34	9.87	10.49	12.10
41 to <51	753	6.07	2.97	3.41	3.92	4.82	8.56	10.19	10.79	12.68
51 to <61	627	5.64	3.21	3.44	4.03	4.79	7.59	8.94	9.75	12.09
61 to <71	678	5.49	3.50	3.82	4.58	5.29	6.41	7.40	7.95	10.23
71 to <81	496	4.96	3.45	3.75	4.29	4.81	5.59	6.26	6.59	9.90
≥81	255	4.86	3.54	3.71	4.17	4.74	5.39	6.33	6.59	7.56
Moderate Intensity Activities (3.0< METS ≤6.0)										
Birth to <1	419	3.67	0.63	0.97	1.74	4.20	5.20	5.80	6.21	7.52
1	308	4.04	0.45	0.59	1.14	5.29	6.06	6.61	6.94	7.68
2	261	3.83	0.59	0.76	1.23	4.74	5.37	5.82	6.15	7.40
3 to <6	540	3.15	0.55	0.75	1.30	3.80	4.52	5.11	5.32	6.30
6 to <11	940	2.66	0.65	0.92	1.65	2.68	3.57	4.36	4.79	5.95
11 to <16	1,337	2.35	0.88	1.09	1.66	2.30	3.02	3.62	3.89	5.90
16 to <21	1,241	3.35	1.13	1.42	2.19	3.45	4.37	5.24	5.59	6.83
21 to <31	701	5.24	1.15	1.58	2.52	6.01	7.15	7.95	8.39	9.94
31 to <41	728	5.69	1.26	1.65	2.84	6.67	7.75	8.45	8.90	9.87
41 to <51	753	5.40	1.21	1.55	2.39	6.46	7.57	8.40	8.85	10.52
51 to <61	627	5.00	1.29	1.63	2.72	5.68	6.75	7.60	8.01	9.94
61 to <71	678	3.73	1.62	1.97	2.81	3.70	4.67	5.45	6.01	7.45
71 to <81	496	2.87	1.56	1.83	2.28	2.86	3.45	3.95	4.31	5.44
≥81	255	2.35	1.32	1.45	1.79	2.29	2.85	3.28	3.61	4.37

Table 6-21. Descriptive Statistics for Duration of Time (hours/day) Spent Performing Activities Within the Specified Activity Category, by Age for Males[a] (continued)

Age Group (years)	*N*	Mean	Duration (hours/day) Spent at Activity — Percentiles 5th	10th	25th	50th	75th	90th	95th	Maximum
High Intensity (METS >6.0)										
Birth to <1	183	0.20	0.00	0.00	0.01	0.14	0.28	0.50	0.59	0.96
1	164	0.31	0.01	0.01	0.03	0.22	0.56	0.78	0.93	1.52
2	162	0.10	0.00	0.01	0.03	0.05	0.14	0.25	0.33	0.48
3 to <6	263	0.27	0.02	0.03	0.04	0.13	0.33	0.75	1.16	1.48
6 to <11	637	0.32	0.01	0.01	0.03	0.13	0.38	1.10	1.50	3.20
11 to <16	1,111	0.38	0.03	0.04	0.10	0.21	0.47	1.03	1.34	2.35
16 to <21	968	0.40	0.03	0.04	0.14	0.27	0.53	0.99	1.29	2.59
21 to <31	546	0.33	0.02	0.05	0.11	0.27	0.45	0.69	0.85	1.95
31 to <41	567	0.38	0.03	0.07	0.14	0.28	0.51	0.83	1.03	1.77
41 to <51	487	0.34	0.03	0.05	0.09	0.23	0.50	0.78	1.00	2.40
51 to <61	452	0.41	0.03	0.05	0.13	0.34	0.59	0.87	1.13	1.95
61 to <71	490	0.37	0.03	0.05	0.13	0.28	0.49	0.80	1.08	2.21
71 to <81	343	0.39	0.01	0.03	0.10	0.29	0.57	0.90	1.11	2.06
≥81	168	0.32	0.02	0.03	0.08	0.25	0.47	0.71	0.88	1.76

[a] Individual measures are weighted by their 4-year sampling weights as assigned within NHANES 1999−2000 when calculating the statistics in this table. Ventilation rate was estimated using a multiple linear regression model.

N = Number of individuals.
MET = Metabolic equivalent.

Source: U.S. EPA (2009a).

Table 6-22. Descriptive Statistics for Duration of Time (hours/day) Spent Performing Activities Within the Specified Activity Category, by Age for Females[a]										
			Duration (hours/day) Spent at Activity							
			Percentiles							
Age Group (years)	*N*	Mean	5th	10th	25th	50th	75th	90th	95th	Maximum
Sleep or nap (Activity ID = 14500)										
Birth to <1	415	12.99	12.00	12.16	12.53	12.96	13.44	13.82	14.07	14.82
1	245	12.58	11.59	11.88	12.29	12.63	12.96	13.16	13.31	14.55
2	255	12.09	11.45	11.68	11.86	12.08	12.34	12.57	12.66	13.48
3 to <6	543	11.13	10.45	10.70	10.92	11.12	11.38	11.58	11.75	12.23
6 to <11	894	10.26	9.55	9.73	10.01	10.27	10.54	10.74	10.91	11.43
11 to <16	1,451	9.57	8.82	8.97	9.27	9.55	9.87	10.17	10.31	11.52
16 to <21	1,182	9.08	8.26	8.44	8.74	9.08	9.39	9.79	10.02	11.11
21 to <31	1,023	8.60	7.89	7.99	8.26	8.59	8.90	9.20	9.38	10.35
31 to <41	869	8.31	7.54	7.70	7.98	8.28	8.59	8.92	9.17	10.22
41 to <51	763	8.32	7.58	7.75	7.99	8.31	8.63	8.93	9.13	10.02
51 to <61	622	8.12	7.36	7.53	7.81	8.11	8.43	8.73	8.85	9.29
61 to <71	700	8.40	7.67	7.88	8.15	8.40	8.68	8.93	9.09	9.80
71 to <81	470	8.58	7.85	8.01	8.26	8.55	8.89	9.19	9.46	10.34
≥81	306	9.11	8.35	8.53	8.84	9.10	9.34	9.73	10.04	10.55
Sedentary and Passive Activities (METS ≤1.5—Includes Sleep or Nap)										
Birth to <1	415	14.07	12.86	13.05	13.53	14.08	14.54	15.08	15.49	16.14
1	245	14.32	13.02	13.25	13.73	14.31	14.88	15.36	15.80	16.40
2	255	14.86	13.81	13.95	14.44	14.81	15.32	15.78	16.03	16.91
3 to <6	543	14.27	12.88	13.15	13.56	14.23	14.82	15.43	15.85	17.96
6 to <11	894	13.97	12.49	12.74	13.22	13.82	14.50	15.34	16.36	18.68
11 to <16	1,451	14.19	12.38	12.76	13.34	14.05	14.82	15.87	16.81	19.27
16 to <21	1,182	13.58	11.80	12.17	12.79	13.52	14.29	15.08	15.67	16.96
21 to <31	1,023	12.59	10.97	11.29	11.88	12.60	13.21	13.75	14.19	16.24
31 to <41	869	12.29	10.91	11.14	11.61	12.24	12.91	13.50	13.90	15.18
41 to <51	763	12.22	10.78	11.08	11.56	12.18	12.82	13.40	13.79	15.17
51 to <61	622	12.66	11.08	11.40	12.08	12.64	13.30	13.89	14.12	15.80
61 to <71	700	14.25	12.89	13.16	13.68	14.22	14.86	15.38	15.69	17.14
71 to <81	470	15.38	13.66	14.20	14.76	15.41	16.05	16.62	16.94	17.90
≥81	306	16.48	14.87	15.09	15.80	16.59	17.15	17.71	18.07	19.13

Table 6-22. Descriptive Statistics for Duration of Time (hours/day) Spent Performing Activities Within the Specified Activity Category, by Age for Females[a] (continued)

Age Group (years)	*N*	Mean	Duration (hours/day) Spent at Activity — Percentiles 5th	10th	25th	50th	75th	90th	95th	Maximum
Light Intensity Activities (1.5< METS ≤3.0)										
Birth to <1	415	6.00	3.49	3.70	4.26	5.01	8.43	9.31	9.77	10.53
1	245	5.61	2.83	2.94	3.46	4.39	8.28	9.03	9.39	10.57
2	255	5.78	3.20	3.54	4.29	5.33	7.48	8.46	8.74	9.93
3 to <6	543	6.25	3.78	4.10	4.79	5.84	7.86	8.84	9.38	10.32
6 to <11	894	7.27	4.63	5.46	6.33	7.17	8.34	9.42	9.79	11.06
11 to <16	1,451	7.55	4.89	5.62	6.75	7.67	8.55	9.27	9.57	10.85
16 to <21	1,182	6.98	4.60	5.08	5.91	6.85	7.96	9.16	9.57	12.29
21 to <31	1,023	6.42	3.66	4.09	4.84	5.82	8.18	9.56	10.14	12.11
31 to <41	869	6.51	4.06	4.33	5.06	5.98	8.14	9.46	9.93	13.12
41 to <51	763	6.56	3.99	4.30	4.97	5.90	8.40	9.75	10.18	11.83
51 to <61	622	6.52	4.09	4.42	5.19	6.05	7.95	9.12	9.43	11.58
61 to <71	700	6.23	4.40	4.74	5.47	6.23	6.96	7.67	8.17	11.13
71 to <81	470	5.96	4.22	4.51	5.24	5.92	6.63	7.46	7.91	9.43
≥81	306	5.3	3.67	3.96	4.63	5.16	6.00	6.70	7.01	8.78
Moderate Intensity Activities (3.0< METS ≤6.0)										
Birth to <1	415	3.91	0.53	0.74	1.10	4.87	5.77	6.27	6.54	7.68
1	245	4.02	0.52	0.73	1.08	5.14	6.10	7.00	7.37	8.07
2	255	3.27	0.50	0.78	1.22	4.01	4.88	5.35	5.57	6.93
3 to <6	543	3.35	0.70	0.89	1.61	3.88	4.71	5.29	5.65	7.58
6 to <11	894	2.57	0.65	0.95	1.82	2.66	3.41	3.95	4.32	6.10
11 to <16	1,451	2.01	0.89	1.08	1.45	1.96	2.51	3.03	3.28	4.96
16 to <21	1,182	3.26	1.27	1.48	2.21	3.39	4.24	4.74	5.07	6.68
21 to <31	1,023	4.80	1.62	1.94	2.78	5.37	6.42	7.19	7.52	9.21
31 to <41	869	5.00	1.71	2.06	3.09	5.41	6.60	7.31	7.58	9.59
41 to <51	763	5.05	1.75	2.00	2.97	5.48	6.66	7.50	7.97	10.16
51 to <61	622	4.58	1.71	2.13	3.10	4.79	5.98	6.89	7.14	8.97
61 to <71	700	3.31	1.65	1.97	2.56	3.34	4.01	4.61	5.01	6.90
71 to <81	470	2.48	1.19	1.36	1.82	2.48	2.99	3.64	4.01	5.63
≥81	306	2.06	1.01	1.25	1.55	1.99	2.51	3.07	3.44	4.68

Table 6-22. Descriptive Statistics for Duration of Time (hours/day) Spent Performing Activities Within the Specified Activity Category, by Age for Females[a] (continued)

Age Group (years)	*N*	Mean	Duration (hours/day) Spent at Activity — Percentiles 5th	10th	25th	50th	75th	90th	95th	Maximum
High Intensity (METS >6.0)										
Birth to <1	79	0.17	0.03	0.05	0.09	0.14	0.21	0.33	0.40	0.58
1	55	0.22	0.03	0.05	0.09	0.18	0.35	0.40	0.43	0.48
2	130	0.15	0.00	0.01	0.03	0.08	0.16	0.48	0.65	1.01
3 to <6	347	0.19	0.01	0.02	0.05	0.10	0.22	0.46	0.73	1.43
6 to <11	707	0.24	0.02	0.03	0.06	0.12	0.26	0.67	0.98	1.71
11 to <16	1,170	0.30	0.03	0.04	0.08	0.19	0.40	0.66	0.96	3.16
16 to <21	887	0.24	0.01	0.03	0.08	0.18	0.34	0.51	0.60	1.61
21 to <31	796	0.26	0.03	0.05	0.10	0.19	0.36	0.56	0.67	1.40
31 to <41	687	0.25	0.03	0.05	0.09	0.19	0.33	0.52	0.72	1.40
41 to <51	515	0.26	0.03	0.04	0.09	0.20	0.36	0.55	0.68	1.49
51 to <61	424	0.34	0.03	0.04	0.12	0.28	0.50	0.74	0.85	1.58
61 to <71	465	0.32	0.03	0.04	0.10	0.23	0.46	0.68	0.89	1.77
71 to <81	304	0.29	0.03	0.05	0.10	0.25	0.43	0.60	0.71	1.24
≥81	188	0.26	0.02	0.03	0.09	0.21	0.38	0.59	0.71	1.23

[a] Individual measures are weighted by their 4-year sampling weights as assigned within NHANES 1999−2000 when calculating the statistics in this table. Ventilation rate was estimated using a multiple linear regression model.

N = Number of individuals.
MET = Metabolic equivalent.

Source: U.S. EPA (2009a).

Table 6-23. Mean Inhalation Rate Values (m^3/day) From Key Studies for Males and Females Combined

Age Group[a]	U.S. EPA (2009a)[b]		Brochu et al. (2006b)[b]		Arcus-Arth and Blaisdell (2007)[b]		Stifelman (2007)[c]		Combined Key Studies[d]	
	N[c]	Mean	*N*	Mean	*N*	Mean	*N*	Mean	*N*	Mean
Birth to <1 month	-	-	-	-	182	3.63	-	-	182	3.63
1 to <3 months	-	-	85	3.31	182	3.63	-	-	267	3.47
3 to <6 months	-	-	85	3.31	294	4.92	-	-	379	4.11
6 to <12 months	-	-	103	4.06	544	6.78	-	-	647	5.42
Birth to <1 year	834	8.64	188	3.72	1,020	5.70	-	3.4	2,042	5.36
1 to <2 years	553	13.41	101	4.90	934	8.77	-	4.9	1,588	7.99
2 to <3 years	516	12.99	61	7.28	989	9.76	-	5.7	1,566	8.93
3 to <6 years	1,083	12.40	61	7.28	4,107	11.22	-	9.3	5,251	10.05
6 to <11 years	1,834	12.93	199	9.98	1,553	13.42	-	11.5	3,586	11.96
11 to <16 years	2,788	14.34	117	14.29	975	16.98	-	15.0	3,880	15.17
16 to <21 years	2,423	15.44	117	14.29	495	18.29	-	17.0	3,035	16.25
21 to <31 years	1,724	16.30	219	14.59	-	-	-	16.3	1,943	15.74
31 to <41 years	1,597	17.40	100	14.99	-	-	-	15.6	1,697	16.00
41 to <51 years	1,516	18.55	91	13.74	-	-	-	15.6	1,607	15.96
51 to <61 years	1,249	18.56	91	13.74	-	-	-	14.7	1,340	15.66
61 to <71 years	1,378	15.43	186	12.57	-	-	-	14.7	1,564	14.23
71 to <81 years	966	14.25	95	11.46	-	-	-	-	1,061	12.86
≥81 years	561	12.97	95	11.46	-	-	-	-	656	12.21

[a] When age groupings in the original reference did not match the U.S. EPA groupings used for this handbook, means from all age groupings in the original reference that overlapped U.S. EPA's age groupings by more than 1 year were averaged, weighted by the number of observations contributed from each age group. See Table 6-25 for concordance with U.S. EPA age groupings.
[b] Weighted (where possible) average of reported study means.
[c] The total number of subjects for Stifelman (2007) was 3,007.
[d] Unweighted average of means from key studies.

Table 6-24. 95th Percentile Inhalation Rate Values (m³/day) From Key Studies for Males and Females Combined										
Age Group[a]	U.S. EPA (2009a)[b]		Brochu et al. (2006b)[b]		Arcus-Arth and Blaisdell (2007)[b]		Stifelman (2007)[c]		Combined Key Studies[d]	
	N[a]	95th	*N*	95th	*N*	95th	*N*	95th	*N*	95th
Birth to <1 month	-[b]	-	-	-	182	7.10	-	-	182	7.10
1 to <3 months	-	-	85	4.44	182	7.10	-	-	267	5.77
3 to <6 months	-	-	85	4.44	294	7.72	-	-	379	6.08
6 to <12 months	-	-	103	5.28	544	10.81	-	-	647	8.04
Birth to <1 year	834	12.67	188	4.90	1,020	9.95	-	-	2,042	9.17
1 to <2 years	553	18.22	101	6.43	934	13.79	-	-	1,588	12.81
2 to <3 years	516	17.04	61	9.27	989	14.81	-	-	1,566	13.71
3 to <6 years	1,083	15.17	61	9.27	4,107	17.09	-	-	5,251	13.84
6 to <11 years	1,834	17.05	199	12.85	1,553	19.86	-	-	3,586	16.59
11 to <16 years	2,788	19.23	117	19.02	975	27.53	-	-	3,880	21.93
16 to <21 years	2,423	20.89	117	19.02	495	33.99	-	-	3,035	24.63
21 to <31 years	1,724	23.57	219	19.00	-	-	-	-	1,943	21.29
31 to <41 years	1,597	24.30	100	18.39	-	-	-	-	1,697	21.35
41 to <51 years	1,516	24.83	91	17.50	-	-	-	-	1,607	21.16
51 to <61 years	1,249	25.17	91	17.50	-	-	-	-	1,340	21.33
61 to <71 years	1,378	19.76	186	16.37	-	-	-	-	1,564	18.07
71 to <81 years	966	17.88	95	15.30	-	-	-	-	1,061	16.59
≥81 years	561	16.10	95	15.30	-	-	-	-	656	15.70

a When age groupings in the original reference did not match the U.S. EPA groupings used for this handbook, 95th percentiles from all age groupings in the original reference that overlapped U.S. EPA's age groupings by more than 1 year were averaged, weighted by the number of observations contributed from each age group. See Table 6-25 for concordance with U.S. EPA age groupings.

b Weighted (where possible) average of reported study 95th percentiles.

c The total number of subjects for Stifelman (2007) was 3,007.

d Unweighted average of 95th percentiles from key studies.

Table 6-25. Concordance of Age Groupings Among Key Studies				
Age Group[a]	U.S. EPA (2009a)	Brochu et al. (2006b)	Arcus-Arth and Blaisdell (2007)	Stifelman (2007)
Birth to <1 month	—	—	0 to 2 months	—
1 to <3 months	—	0.22 to <0.5 year	0 to 2 months	—
3 to <6 months	—	0.22 to <0.5 year	3 to 5 months	—
6 to <12 months	—	0.5 to <1 year	6 to 8 months	—
	—	—	9 to 11 months	—
Birth to <1 year	Birth to <1 year	0.22 to <0.5 year	0 to 11 months	<1 year
	—	0.5 to <1 year	—	—
1 to <2 years	1 to <2 years	1 to <2 years	1 year	1 year
2 to <3 years	2 to <3 years	2 to <5 years	2 years	2 years
3 to <6 years	3 to <6 years	2 to <5 years	3 years	3 years
	—	—	4 years	4 years
	—	—	5 years	5 years
6 to <11 years	6 to <11 years	7 to <11 years	6 years	6 years
	—	—	7 years	7 years
	—	—	8 years	8 years
	—	—	9 years	9 years
	—	—	10 years	10 years
11 to <16 years	11 to <16 years	11 to <23 years	11 years	11 years
	—	—	12 years	12 years
	—	—	13 years	13 years
	—	—	14 years	14 years
	—	—	15 years	15 years
16 to <21 years	16 to <21 years	11 to <23 years	16 years	16 years
	—	—	17 years	17 years
	—	—	18 years	18 years
	—	—	—	19 to 30 years
21 to <31 years	21 to <31 years	11 to <23 years	—	19 to 30 years
	—	23 to <30 years	—	—
31 to <41 years	31 to <41 years	30 to <40 years	—	31 to 50 years
41 to <51 years	41 to <51 years	40 to <65 years	—	31 to 50 years
51 to <61 years	51 to <61 years	40 to <65 years	—	51 to 70 years
61 to <71 years	61 to <71 years	40 to <65 years	—	51 to 70 years
	—	65 to ≤96 years	—	—
71 to <81 years	71 to <81 years	65 to ≤96 years	—	—
≥81 years	≥81 years	65 to ≤96 years	—	—

[a] When age groups in the original reference did not match the U.S. EPA groupings used for this handbook, statistics were averaged from all age groupings in the original reference that overlapped U.S. EPA's age groupings by more than 1 year, weighted by the number of observations contributed from each age group. For example, Brochu et al. (2006b) contributes its 2 to <5-year age group data to both U.S. EPA's 2 to <3-year and 3 to <6-year age groups.

Table 6-26. Time Weighted Average of Daily Inhalation Rates (DIRs) Estimated From Daily Activities[a]

Subject	Inhalation Rate (m^3/hour)		DIR[b] (m^3/day)
	Resting	Light Activity	
Adult Man	0.45	1.2	22.8
Adult Woman	0.36	1.14	21.1
Child (10 years)	0.29	0.78	14.8
Infant (1 year)	0.09	0.25	3.76
Newborn	0.03	0.09	0.78

[a] Assumptions made were based on 8 hr resting and 16 hr light activity for adults and children (10 years); 14 hr resting and 10 hr light activity for infants (1 year); 23 hr resting and 1 hr light activity for newborns.

[b]

$$DIR = \frac{1}{T}\sum_{i=1}^{K} IR_i t_i$$

DIR = Daily Inhalation Rate,
IR_i = Corresponding inhalation rate at i^{th} activity,
t_i = Hours spent during the i^{th} activity,
k = Number of activity periods, and
T = Total time of the exposure period (i.e., a day).

Source: ICRP (1981).

Table 6-27. Selected Inhalation Rate Values During Different Activity Levels Obtained From Various Literature Sources

Subject	BW (kg)	Resting			Light Activity			Heavy Work			Maximal Work During Exercise		
		f	VT	V*	f	VT	V*	f	VT	V*	f	VT	V*
Adolescent													
Male, 14−16 years		16	330	5.2							53	2,520	113
Male, 14−15 years	59.4												
Female, 14−16 years		15	300	4.5									
Female, 14−15 years; 164.9 cm L	56										52	1,870	88
Children													
10 year; 140 cm L		16	300	4.8	24	600	14						
Males, 10−11 years	36.5										58	1,330	71
Males, 10−11 years; 140.6 cm L	32.5										61	1,050	61
Females, 4−6 years	20.8										70	600	40
Females, 4−6 years; 111.6 cm L	18.4										66	520	34
Infant, 1 year		30	48	1.4[a]									
Newborn	2.5	34	15	0.5									
20 hours−13 weeks	2.5−5.3										68[b]	51[a,b]	3.5[b]
9.6 hours	3.6	25	21	0.5									
6.6 days	3.7	29	21	0.6									
Adult													
Man	68.5	12	750	7.4	17	1,670	29	21	2,030	43			
1.7 m^2 SA		12	500	6									
30 years; 170 cm L		15	500	7.5	16	1,250	20						
20−33 years	70.4										40	3,050	111
Woman	54	12	340	4.5	19	860	16	30	880	25			
30 years; 160 cm L		15	400	6	20	940	19						
20−25 years; 165.8 cm L	60.3										46	2,100	90
Pregnant (8th month)		16	650	10									

[a] Calculated from $V^* = f \times VT$.
[b] Crying.

BW = body weights.
f = frequency (breaths/minute).
VT = tidal volume (mL).
V* = minute volume (L/minute).
cm L = length/height.

Source: ICRP (1981).

Table 6-28. Summary of Human Inhalation Rates by Activity Level (m^3/hour)[a]

	N[b]	Resting[c]	*N*[b]	Light[d]	*N*[b]	Moderate[e]	*N*[b]	Heavy[f]
Child, 6 years	8	0.4	16	0.8	4	2.0	5	2.3
Child, 10 years	10	0.4	40	1.0	29	3.2	43	3.9
Adult male	454	0.7	102	0.8	102	2.5	267	4.8
Adult female	595	0.3	786	0.5	106	1.6	211	2.9
Average adult	1,049	0.5	888	0.6	208	2.1	478	3.9

[a] Values of inhalation rates for children (male and female) presented in this table represent the mean of values reported for each activity level in 1985.
[b] Number of observations at each activity level.
[c] Includes watching television, reading, and sleeping.
[d] Includes most domestic work, attending to personal needs and care, hobbies, and conducting minor indoor repairs and home improvements.
[e] Includes heavy indoor cleanup, performance of major indoor repairs and alterations, and climbing stairs.
[f] Includes vigorous physical exercise and climbing stairs carrying a load.

Source: Adapted from U.S. EPA (1985).

Table 6-29. Estimated Minute Ventilation Associated With Activity Level for Average Male Adult[a]

Level of work	L/minute	Representative activities
Light	13	Level walking at 2 mph; washing clothes
Light	19	Level walking at 3 mph; bowling; scrubbing floors
Light	25	Dancing; pushing wheelbarrow with 15-kg load; simple construction; stacking firewood
Moderate	30	Easy cycling; pushing wheelbarrow with 75-kg load; using sledgehammer
Moderate	35	Climbing stairs; playing tennis; digging with spade
Moderate	40	Cycling at 13 mph; walking on snow; digging trenches
Heavy	55	Cross-country skiing; rock climbing; stair climbing
Heavy	63	with load; playing squash or handball; chopping
Very heavy	72	with axe
Very heavy	85	Level running at 10 mph; competitive cycling
Severe	100+	Competitive long distance running; cross-country skiing

[a] Average adult assumed to weigh 70 kg.

Source: Adapted from U.S. EPA (1985).

Table 6-30. Activity Pattern Data Aggregated for Three Microenvironments by Activity Level for All Age Groups		
Microenvironment	Activity Level	Average Hours Per Day in Each Microenvironment at Each Activity Level
Indoors	Resting	9.82
	Light	9.82
	Moderate	0.71
	Heavy	0.10
	TOTAL	20.4
Outdoors	Resting	0.51
	Light	0.51
	Moderate	0.65
	Heavy	0.12
	TOTAL	1.77
In Transportation Vehicle	Resting	0.86
	Light	0.86
	Moderate	0.05
	Heavy	0.0012
	TOTAL	1.77

Source: Adapted from U.S. EPA (1985).

Table 6-31. Summary of Daily Inhalation Rates (DIRs) Grouped by Age and Activity Level

Subject	Daily Inhalation Rate (m^3/day)[a]				Total Daily IR[b] (m^3/day)
	Resting	Light	Moderate	Heavy	
Child, 6 years	4.47	8.95	2.82	0.50	16.74
Child, 10 years	4.47	11.19	4.51	0.85	21.02
Adult Male	7.83	8.95	3.53	1.05	21.4
Adult Female	3.35	5.59	2.26	0.64	11.8
Adult Average	5.60	6.71	2.96	0.85	16

[a] Daily inhalation rate was calculated using the following equation:

$$IR = \frac{1}{T}\sum_{i=1}^{k} IRt_i$$

IR_i = Inhalation rate at i^{th} activity,
t_i = Hours spent per day during i^{th} activity,
k = Number of activity periods, and
T = Total time of the exposure period (e.g., a day).

[b] Total daily inhalation rate was calculated by summing the specific activity (resting, light, moderate, heavy) and dividing them by the total amount of time spent on all activities.

Source: Generated using the data from U.S. EPA (1985) as shown in Table 6-28 and Table 6-30.

Table 6-32. Distribution Pattern of Predicted Ventilation Rate (VR) and Equivalent Ventilation Rate (EVR) for 20 Outdoor Workers

Self-Reported Activity Level	*N*[c]	VR (m^3/hour)[a] Arithmetic Mean ± SD	VR (m^3/hour)[a] Geometric Mean ± SD	EVR[b] (m^3/hour/m^2 body surface) Arithmetic Mean ± SD	EVR[b] (m^3/hour/m^2 body surface) Geometric Mean ± SD		
Sleep	18,597	0.42 ± 0.16	0.39 ± 0.08	0.23 ± 0.08	0.22 ± 0.08		
Slow	41,745	0.71 ± 0.4	0.65 ± 0.09	0.38 ± 0.20	0.35 ± 0.09		
Medium	3,898	0.84 ± 0.47	0.76 ± 0.09	0.48 ± 0.24	0.44 ± 0.09		
Fast	572	2.63 ± 2.16	1.87 ± 0.14	1.42 ± 1.20	1.00 ± 0.14		
Percentile Rankings, VR							
	1	5	10	50	90	95	99	99.9
Sleep	0.18	0.18	0.24	0.36	0.66	0.72	0.90	1.20
Slow	0.30	0.36	0.36	0.66	1.08	1.32	1.98	4.38
Medium	0.36	0.42	0.48	0.72	1.32	1.68	2.64	3.84
Fast	0.42	0.54	0.60	1.74	5.70	6.84	9.18	10.26
Percentile Rankings, EVR								
	1	5	10	50	90	95	99	99.9
Sleep	0.12	0.12	0.12	0.24	0.36	0.36	0.48	0.60
Slow	0.18	0.18	0.24	0.36	0.54	0.66	1.08	2.40
Medium	0.18	0.24	0.30	0.42	0.72	0.90	1.38	2.28
Fast	0.24	0.30	0.36	0.90	3.24	3.72	4.86	5.52

a Data presented by Shamoo et al. (1991) in L/minute were converted to m^3/hour.

b EVR = VR per square meter of body surface area.

c Number of minutes with valid appearing heart rate records and corresponding daily records of breathing rate.

Source: Shamoo et al. (1991).

Table 6-33. Distribution Pattern of Inhalation Rate by Location and Activity Type for 20 Outdoor Workers

Location	Activity Type[a]	Self-Reported Activity Level	% of Time	Inhalation rate (m^3/hour)[b] ± SD	% of Avg.[c]
Indoor	Essential	Sleep	28.7	0.42 ± 0.12	69 ± 15
		Slow	29.5	0.72 ± 0.36	106 ± 43
		Medium	2.4	0.72 ± 0.30	129 ± 38
		Fast	0	0	0
Indoor	Non-essential	Slow	20.4	0.66 ± 0.36	98 ± 36
		Medium	0.9	0.78 ± 0.30	120 ± 50
		Fast	0.2	1.86 ± 0.96	278 ± 124
Outdoor	Essential	Slow	11.3	0.78 ± 0.36	117 ± 42
		Medium	1.8	0.84 ± 0.54	130 ± 56
		Fast	0	0	0
Outdoor	Non-essential	Slow	3.2	0.90 ± 0.66	136 ± 90
		Medium	0.8	1.26 ± 0.60	213 ± 91
		Fast	0.7	2.82 ± 2.28	362 ± 275

[a] Essential activities include income-related work, household chores, child care, study and other school activities, personal care, and destination-oriented travel; Non-essential activities include sports and active leisure, passive leisure, some travel, and social or civic activities.

[b] Data presented by Shamoo et al. (1991) in L/min were converted to m^3/hour.

[c] Statistic was calculated by converting each VR for a given subject to a percentage of her/his overall average.

Source: Adapted from Shamoo et al. (1991).

Table 6-34. Calibration and Field Protocols for Self-Monitoring of Activities Grouped by Subject Panels		
Panel	Calibration Protocol	Field Protocol
Panel 1: Healthy Outdoor Workers—15 female, 5 male, age 19−50	Laboratory treadmill exercise tests, indoor hallway walking tests at different self-chosen speeds, 2 outdoor tests consisted of 1-hour cycles each of rest, walking, and jogging.	3 days in 1 typical summer week (included most active workday and most active day off); HR recordings and activity diary during waking hours.
Panel 2: Healthy Elementary School Students—5 male, 12 female, ages 10−12	Outdoor exercises each consisted of 20 minute rest, slow walking, jogging and fast walking.	Saturday, Sunday and Monday (school day) in early autumn; heart rate recordings and activity diary during waking hours and during sleep.
Panel 3: Healthy High School Students—7 male, 12 female, ages 13−17	Outdoor exercises each consisted of 20 minute rest, slow walking, jogging and fast walking.	Same as Panel 2, however, no heart rate recordings during sleep for most subjects.
Panel 4: Adult Asthmatics, clinically mild, moderate, and severe—15 male, 34 female, age 18−50	Treadmill and hallway exercise tests.	1 typical summer week, 1 typical winter week; hourly activity/health diary during waking hours; lung function tests 3 times daily; HR recordings during waking hours on at least 3 days (including most active work day and day off).
Panel 5: Adult Asthmatics from 2 neighborhoods of contrasting O_3 air quality—10 male, 14 female, age 19−46	Treadmill and hallway exercise tests.	Similar to Panel 4, personal NO_2 and acid exposure monitoring included. (Panels 4 and 5 were studied in different years, and had 10 subjects in common).
Panel 6: Young Asthmatics—7 male, 6 female, ages 11−16	Laboratory exercise tests on bicycles and treadmills.	Summer monitoring for 2 successive weeks, including 2 controlled exposure studies with few or no observable respiratory effects.
Panel 7: Construction Workers—7 male, age 26−34	Performed similar exercises as Panel 2 and 3, and also performed job-related tests including lifting and carrying a 9-kg pipe.	HR recordings and diary information during 1 typical summer work day.
Source: Linn et al. (1992).		

Table 6-35. Subject Panel Inhalation Rates by Mean Ventilation Rate (VR), Upper Percentiles, and Self-Estimated Breathing Rates

Panel Number and Description	N[a]	Inhalation Rates (m^3/hour)				
		Mean VR	99th Percentile VR	Mean VR at Activity Levels[b]		
				Slow	Medium	Fast
Healthy						
1—Adults	20	0.78	2.46	0.72	1.02	3.06
2—Elementary School Students	17	0.90	1.98	0.84	0.96	1.14
3—High School Students	19	0.84	2.22	0.78	1.14	1.62
7—Construction Workers[c]	7	1.50	4.26	1.26	1.50	1.68
Asthmatics						
4—Adults	49	1.02	1.92	1.02	1.68	2.46
5—Adults[d]	24	1.20	2.40	1.20	2.04	4.02
6—Elementary and High School Students	13	1.20	2.40	1.20	1.20	1.50

a Number of individuals in each survey panel.
b Some subjects did not report medium and/or fast activity. Group means were calculated from individual means (i.e., give equal weight to each individual who recorded any time at the indicated activity level).
c Construction workers recorded only on 1 day, mostly during work, while others recorded on ≥1 work or school day and ≥1 day off.
d Excluding subjects also in Panel 4.

VR = Ventilation rate.

Source: Linn et al. (1992).

Table 6-36. Actual Inhalation Rates Measured at Four Ventilation Levels

Subject	Location	Mean Inhalation Rate[a] (m^3/hour)			
		Low	**Medium**	**Heavy**	**Very Heavy**
All subjects	Indoor (treadmill post)	1.23	1.83	3.13	4.13
	Outdoor	0.88	1.96	2.93	4.90
	Total	0.93	1.92	3.01	4.80

a Original data were presented in L/minute. Conversion to m^3/hour was obtained as follows:

L/minute × 0.001 m^3/L × 60 minute/hour = m^3/hour

Source: Adapted from Shamoo et al. (1992).

Table 6-37. Distribution of Predicted Inhalation Rates by Location and Activity Levels for Elementary and High School Students

Age (years)	Student	Location	Activity Level	% Recorded Time[a]	Inhalation Rates (m^3/hour) Mean ± SD	Percentile Rankings[b] 1st	50th	99.9th
10−12	EL[c]	Indoors	slow	49.6	0.84 ± 0.36	0.18	0.78	2.34
	(N[d] = 17)		medium	23.6	0.96 ± 0.36	0.24	0.84	2.58
			fast	2.4	1.02 ± 0.60	0.24	0.84	3.42
		Outdoors	slow	8.9	0.96 ± 0.54	0.36	0.78	4.32
			medium	11.2	1.08 ± 0.48	0.24	0.96	3.36
			fast	4.3	1.14 ± 0.60	0.48	0.96	3.60
13−17	HS[c]	Indoors	slow	70.7	0.78 ± 0.36	0.30	0.72	3.24
	(N[d] = 19)		medium	10.9	0.96 ± 0.42	0.42	0.84	4.02
			fast	1.4	1.26 ± 0.66	0.54	1.08	6.84[e]
		Outdoors	slow	8.2	0.96 ± 0.48	0.42	0.90	5.28
			medium	7.4	1.26 ± 0.78	0.48	1.08	5.70
			fast	1.4	1.44 ± 1.08	0.48	1.02	5.94

[a] Recorded time averaged about 23 hours per elementary school student and 33 hours per high school student over 72-hour periods.
[b] Geometric means closely approximated 50th percentiles; geometric standard deviations were 1.2−1.3 for HR, 1.5−1.8 for VR.
[c] Elementary school student (EL) or high school student (HS).
[d] Number of students that participated in survey.
[e] Highest single value.

SD = Standard deviation.

Source: Spier et al. (1992).

Table 6-38. Average Hours Spent per Day in a Given Location and Activity Level for Elementary and High School Students

Students	Location	Activity Level: Slow	Medium	Fast	Total Time Spent (hours/day)
Elementary school, ages 10 to 12 years (*N* = 17)	Indoors	16.3	2.9	0.4	19.6
	Outdoors	2.2	1.7	0.5	4.4
High school, ages 13 to 17 years (*N* = 19)	Indoors	19.5	1.5	0.2	21.2
	Outdoors	1.2	1.3	0.2	2.7

N = Number of students that participated in survey.

Source: Spier et al. (1992).

Table 6-39. Distribution Patterns of Daily Inhalation Rates (DIRs) for Elementary (EL) and High School (HS) Students Grouped by Activity Level

Students	Age (years)	Location	Activity Type[a]	Mean IR[b] (m^3/day)	Percentile Rankings: 1st	50th	99.9th
EL (*N*[c] = 17)	10 to 12	Indoor	Light	13.7	2.93	12.71	38.14
			Moderate	2.8	0.70	2.44	7.48
			Heavy	0.4	0.10	0.34	1.37
EL		Outdoor	Light	2.1	0.79	1.72	9.5
			Moderate	1.84	0.41	1.63	5.71
			Heavy	0.57	0.24	0.48	1.80
HS (*N* = 19)	13 to 17	Indoor	Light	15.2	5.85	14.04	63.18
			Moderate	1.4	0.63	1.26	6.03
			Heavy	0.25	0.11	0.22	1.37
HS		Outdoor	Light	1.15	0.5	1.08	6.34
			Moderate	1.64	0.62	1.40	7.41
			Heavy	0.29	0.10	0.20	1.19

[a] For this report, activity type presented in Table 6-37 and Table 6-38 was redefined as light activity for slow, moderate activity for medium, and heavy activity for fast.

[b] Daily inhalation rate was calculated by multiplying the hours spent at each activity level (see Table 6-38) by the corresponding inhalation rate (see Table 6-37).

[c] Number of elementary (EL) and high school students (HS).

Source: Adapted from Spier et al. (1992) (Generated using data from Table 6-37 and Table 6-38).

Table 6-40. Mean Minute Inhalation Rate (m^3/minute) by Group and Activity for Laboratory Protocols

Activity	Young Children[a]	Children[a]	Adult Females[a]	Adult Males[a]	Adults (combined)[a]
Lying	6.19E−03	7.51E−03	7.12E−03	8.93E−03	8.03E−03
Sitting	6.48E−03	7.28E−03	7.72E−03	9.30E−03	8.51E−03
Standing	6.76E−03	8.49E−03	8.36E−03	10.65E−03	9.51E−03
Walking					
1.5 mph	1.03E−02	DNP[b]	DNP	DNP	DNP
1.875 mph	1.05E−02	DNP	DNP	DNP	DNP
2.0 mph	DNP	1.41E−02	DNP	DNP	DNP
2.25 mph	1.17E−02	DNP	DNP	DNP	DNP
2.5 mph	DNP	1.56E−02	2.03E−02	2.41E−02	2.22E−02
3.0 mph	DNP	1.78E−02	2.42E−02	DNP	DNP
3.3 mph	DNP	DNP	DNP	2.79E−02	DNP
4.0 mph	DNP	DNP	DNP	3.65E−02	DNP
Running					
3.5 mph	DNP	2.68E−02	DNP	DNP	DNP
4.0 mph	DNP	3.12E−02	4.60E−02[b]	DNP	DNP
4.5 mph	DNP	3.72E−02	4.79E−02[b]	5.73E−02	5.26E−02
5.0 mph	DNP	DNP	5.08E−02[b]	5.85E−02	5.47E−02
6.0 mph	DNP	DNP	DNP	6.57E−02[b]	DNP

[a] Young children, male and female 3−5.9 year olds; children, male and female 6−12.9 year olds; adult females, adolescent, young to middle-aged, and older adult females; adult males, adolescent, young to middle-aged, and older adult males. DNP, group did not perform this protocol or *N* was too small for appropriate mean comparisons.

[b] Older adults not included in the mean value since they did not perform running protocol at particular speeds.

Source: Adams (1993).

Table 6-41. Mean Minute Inhalation Rate (m^3/minute) by Group and Activity for Field Protocols

Activity	Young Children[a]	Children[a]	Adult Females[a]	Adult Males[a]	Adults (combined)[a]
Play	1.13E−02	1.79E−02	DNP	DNP	DNP
Car Driving	DNP	DNP	8.95E−03	1.08E−02	9.87E−03
Car Riding	DNP	DNP	8.19E−03	9.83E−03	9.01E−03
Yardwork	DNP	DNP	1.92E−02[b]	2.61E−02[c]/3.19E−02[d]	2.27E−02[c]/2.56E−02[d]
Housework	DNP	DNP	1.74E−02	DNP	DNP
Car Maintenance	DNP	DNP	DNP	2.32E−02[e]	DNP
Mowing	DNP	DNP	DNP	3.66E−02[b]	DNP
Woodworking	DNP	DNP	DNP	2.44E−02[b]	DNP

[a] Young children, male and female 3−5.9 year olds; children, male and female 6−12.9 year olds; adult females, adolescent, young to middle-aged, and older adult females; adult males, adolescent, young to middle-aged, and older adult males; DNP, group did not perform this protocol or *N* was too small for appropriate mean comparisons.

[b] Adolescents not included in mean value since they did not perform this activity.

[c] Mean value for young to middle-aged adults only.

[d] Mean value for older adults only.

[e] Older adults not included in the mean value since they did not perform this activity.

Source: Adams (1993).

Table 6-42. Summary of Average Inhalation Rates (m^3/hour) by Age Group and Activity Levels for Laboratory Protocols

Age Group	Activity Level				
	Resting[a]	Sedentary[b]	Light[c]	Moderate[d]	Heavy[e]
Young Children (3−5.9 years) Average inhalation rate (m^3/hour) (*N* = 12, sex not specified)	0.37	0.40	0.65	DNP[f]	DNP
Children (6−12.9 years) Average inhalation rate (m^3/hour) (*N* = 40, 20 male and 20 female)	0.45	0.47	0.95	1.74	2.23
Adults (females) (Adolescent, young to middle aged, and older adult females) (*N* = 37)	0.43	0.48	1.33	2.76	2.96[g]
Adults (males) (Adolescent, young to middle aged, and older adult males) (*N* = 39)	0.54	0.60	1.45	1.93	3.63
Adults (combined) (*N* = 76)	0.49	0.54	1.38	2.35	3.30

[a] Resting defined as lying (see Table 6-40 for original data).
[b] Sedentary defined as sitting and standing (see Table 6-40 for original data).
[c] Light defined as walking at speed level 1.5−3.0 mph (see Table 6-40 for original data).
[d] Moderate defined as fast walking (3.3−4.0 mph) and slow running (3.5−4.0 mph) (see Table 6-40 for original data).
[e] Heavy defined as fast running (4.5−6.0 mph) (see Table 6-40 for original data).
[f] Group did not perform (DNP) this protocol or *N* was too small for appropriate mean comparisons. All young children did not run.
[g] Older adults not included in mean value since they did not perform running protocols at particular speeds.

Source: Adapted from Adams (1993).

Table 6-43. Summary of Average Inhalation Rates (m^3/hour) by Age Group And Activity Levels in Field Protocols

Age Group	Sedentary Activity[a]	Light Activity[b]	Moderate Activity[c]
Young Children (3 to 5.9 years) Average inhalation rate (m^3/hour) (*N* = 12, sex not specified)	DNP	DNP[d]	0.68
Children (6 to 12.9 years) Average inhalation rate (m^3/hour) (*N* = 40, 20 male and 20 female)	DNP	DNP	1.07
Adults (females) (Adolescent, young to middle aged, and older adult females) (*N* = 37)	0.51	1.10[e]	DNP
Adults (males) (Adolescent, young to middle aged, and older adult males) (*N* = 39)	0.62	1.40	1.78[f]
Adults (combined) (*N* = 76)	0.57	1.25	DNP

[a] Sedentary activity was defined as car driving and riding (both sexes) (see Table 6-41 for original data).
[b] Light activity was defined as car maintenance (males), housework (females), and yard work (females) (see Table 6-41 for original data).
[c] Moderate activity was defined as mowing (males); wood working (males); yard work (males); and play (children) (see Table 6-41 for original data).
[d] DNP. Group did not perform this protocol or *N* was too small for appropriate mean comparisons.
[e] Older adults not included in mean value since they did not perform this activity.
[f] Adolescents not included in mean value since they did not perform this activity.

N = Number of individuals.

Source: Adams (1993).

Table 6-44. Comparisons of Estimated Basal Metabolic Rates (BMR) With Average Food-Energy Intakes (EFDs) for Individuals Sampled in the 1977−1978 NFCS

Cohort/Age (years)	Body Weight (kg)	BMR[a]		EFD		Ratio
		MJ/day[b]	Kcal/day[c]	MJ/day	Kcal/day	EFD[d]/BMR
Males and Females						
<1	7.6	1.74	416	3.32	793	1.90
1 to 2	13	3.08	734	5.07	1,209	1.65
3 to 5	18	3.69	881	6.14	1,466	1.66
6 to 8	26	4.41	1,053	7.43	1,774	1.68
Males						
9 to 11	36	5.42	1,293	8.55	2,040	1.58
12 to 14	50	6.45	1,540	9.54	2,276	1.48
15 to 18	66	7.64	1,823	10.8	2,568	1.41
19 to 22	74	7.56	1,804	10.0	2,395	1.33
23 to 34	79	7.87	1,879	10.1	2,418	1.29
35 to 50	82	7.59	1,811	9.51	2,270	1.25
51 to 64	80	7.49	1,788	9.04	2,158	1.21
65 to 74	76	6.18	1,476	8.02	1,913	1.30
≥75	71	5.94	1,417	7.82	1,866	1.32
Females						
9 to 11	36	4.91	1,173	7.75	1,849	1.58
12 to 14	49	5.64	1,347	7.72	1,842	1.37
15 to 18	56	6.03	1,440	7.32	1,748	1.21
19 to 22	59	5.69	1,359	6.71	1,601	1.18
23 to 34	62	5.88	1,403	6.72	1,603	1.14
35 to 50	66	5.78	1,380	6.34	1,514	1.10
51 to 64	67	5.82	1,388	6.40	1,528	1.10
65 to 74	66	5.26	1,256	5.99	1,430	1.14
≥75	62	5.11	1,220	5.94	1,417	1.16

[a] Calculated from the appropriate age and sex-based BMR equations given in Table 6-46.
[b] MJ/day = megajoules/day.
[c] Kcal/day = kilocalories/day.
[d] Food-energy intake (Kcal/day) or (MJ/day).

Source: Layton (1993).

Table 6-45. Daily Inhalation Rates (DIRs) Calculated From Food-Energy Intakes (EFDs)

Cohort/Age (years)	L[b]	Daily Inhalation Rate[c] (m^3/day)	Sleep (hours)	MET[a] Value A[d]	MET[a] Value F[e]	Inhalation Rates Inactive[f] (m^3/day)	Inhalation Rates Active[f] (m^3/day)
Males and Females							
<1	1	4.5	11	1.9	2.7	2.35	6.35
1 to 2	2	6.8	11	1.6	2.2	4.16	9.15
3 to 5	3	8.3	10	1.7	2.2	4.98	10.96
6 to 8	3	10	10	1.7	2.2	5.95	13.09
Males							
9 to 11	3	14	9	1.9	2.5	7.32	18.3
12 to 14	3	15	9	1.8	2.2	8.71	19.16
15 to 18	4	17	8	1.7	2.1	10.31	21.65
19 to 22	4	16	8	1.6	1.9	10.21	19.4
23 to 34	11	16	8	1.5	1.8	10.62	19.12
35 to 50	16	15	8	1.5	1.8	10.25	18.45
51 to 64	14	15	8	1.4	1.7	10.11	17.19
65 to 74	10	13	8	1.6	1.8	8.34	15.01
≥75	1	13	8	1.6	1.9	8.02	15.24
Lifetime average[g]		14					
Females							
9 to 11	3	13	9	1.9	2.5	6.63	16.58
12 to 14	3	12	9	1.6	2.0	7.61	15.22
15 to 18	4	12	8	1.5	1.7	8.14	13.84
19 to 22	4	11	8	1.4	1.6	7.68	12.29
23 to 34	11	11	8	1.4	1.6	7.94	12.7
35 to 50	16	10	8	1.3	1.5	7.80	11.7
51 to 64	14	10	8	1.3	1.5	7.86	11.8
65 to 74	10	9.7	8	1.4	1.5	7.10	10.65
≥75	1	9.6	8	1.4	1.6	6.90	11.04
Lifetime average[g]		10					

[a] MET = Metabolic equivalent.

[b] L is the number of years for each age cohort.

[c] Daily inhalation rate was calculated by multiplying the EFD values (see Table 6-44) by $H \times VQ \times (m^3\ 1{,}000\ L^{-1})$ for subjects under 9 years of age and by $1.2 \times H \times VQ \times (m^3\ 1{,}000\ L^{-1})$ (for subjects 9 years of age and older (see text for explanation).

where:
- *EFD* = (Kcal/day) or (MJ/day),
- *H* = Oxygen uptake = 0.05 L O_2/KJ or 0.21 L O_2/Kcal, and
- *VQ* = Ventilation equivalent = 27 = geometric mean of VQs (unitless).

[d] For individuals 9 years of age and older, A was calculated by multiplying the ratio for EFD/BMR (unitless) (see Table 6-44) by the factor 1.2 (see text for explanation).

[e] $F = (24A - S)/(24 - S)$ (unitless), ratio of the rate of energy expenditure during active hours to the estimated BMR (unitless).

where:
- *S* = Number of hours spent sleeping each day (hours).

[f] Inhalation rate for inactive periods was calculated as $BMR \times H \times VQ \times (d\ 1{,}440\ minute^{-1})$ and for active periods by multiplying inactive inactive inhalation rate by F (See footnote e); BMR values are from Table 6-44.

where:
- *BMR* = Basal metabolic rate (MJ/day) or (kg/hour).

[g] Lifetime average was calculated by multiplying individual inhalation rate by corresponding L values summing the products across cohorts and dividing the result by 75, the total of the cohort age spans.

Source: Layton (1993).

Table 6-46. Statistics of the Age/Sex Cohorts Used to Develop Regression Equations for Predicting Basal Metabolic Rates (BMR)

Sex, Age (years)	BMR MJ d^{-1}	BMR SD	CV	Body Weight (kg)	*N*	BMR Equation[a]	*r*
Males							
Under 3	1.51	0.92	0.61	6.6	162	0.249 BW − 0.127	0.95
3 to <10	4.14	0.50	0.12	21	338	0.095 BW + 2.110	0.83
10 to <18	5.86	1.17	0.20	42	734	0.074 BW + 2.754	0.93
18 to <30	6.87	0.84	0.12	63	2,879	0.063 BW + 2.896	0.65
30 to <60	6.75	0.87	0.13	64	646	0.048 BW + 3.653	0.60
≥60	5.59	0.93	0.17	62	50	0.049 BW + 2.459	0.71
Females							
Under 3	1.54	0.92	0.59	6.9	137	0.244 BW − 0.130	0.96
3 to <10	3.85	0.49	0.13	21	413	0.085 BW + 2.033	0.81
10 to <18	5.04	0.78	0.15	38	575	0.056 BW + 2.898	0.80
18 to <30	5.33	0.72	0.14	53	829	0.062 BW + 2.036	0.73
30 to <60	5.62	0.63	0.11	61	372	0.034 BW + 3.538	0.68
≥60	4.85	0.61	0.12	56	38	0.038 BW + 2.755	0.68

[a] Body weight (BW) in kg.
SD = Standard deviation.
CV = Coefficient of variation (SD/mean).
N = Number of observations.
r = Coefficient of correlation.

Source: Layton (1993).

Table 6-47. Daily Inhalation Rates (DIRs) Obtained From the Ratios of Total Energy Expenditure to Basal Metabolic Rate (BMR)

Sex/Age (years)	Body Weight[a] (kg)	BMR[b] (MJ/day)	*VQ*	*A*[c]	*H* ($m^3 O_2$/MJ)	Inhalation Rate, V_E (m^3/day)[d]
Males						
0.5 to <3	14	3.4	27	1.6	0.05	7.3
3 to <10	23	4.3	27	1.6	0.05	9.3
10 to <18	53	6.7	27	1.7	0.05	15
18 to <30	76	7.7	27	1.59	0.05	17
30 to <60	80	7.5	27	1.59	0.05	16
≥60	75	6.1	27	1.59	0.05	13
Females						
0.5 to <3	11	2.6	27	1.6	0.05	5.6
3 to <10	23	4.0	27	1.6	0.05	8.6
10 to <18	50	5.7	27	1.5	0.05	12
18 to <30	62	5.9	27	1.38	0.05	11
30 to <60	68	5.8	27	1.38	0.05	11
≥60	67	5.3	27	1.38	0.05	9.9

[a] Body weight was based on the average weights for age/sex cohorts in the U.S. population.
[b] The BMRs are calculated using the respective body weights and BMR equations (see Table 6-46).
[c] The values of the BMR multiplier (EFD/BMR) for those 18 years and older were derived from the Basiotis et al. (1989) study: male = 1.59, female = 1.38. For males and females under 10 years old, the mean BMR multiplier used was 1.6. For males and females aged 10 to <18 years, the mean values for *A* given in Table 6-45 for 12−14 years and 15−18 years, age brackets for males and females were used: male = 1.7 and female = 1.5.
[d] Inhalation rate = $BMR \times A \times H \times VQ$; *VQ* = ventilation equivalent and *H* = oxygen uptake.

Source: Layton (1993).

Table 6-48. Daily Inhalation Rates (DIRs) Based on Time-Activity Survey

		Males						Females					
Age (years) and Activity	MET	Body Weight[a] (kg)	BMR[b] (KJ/hour)	Duration[c] (hour/day)	E[d] (MJ/day)	V_E[e] (m^3/day)	V_E[f] (m^3/hour)	Body Weight[a] (kg)	BMR[b] (KJ/hour)	Duration[c] (hour/day)	E[d] (MJ/day)	V_E[e] (m^3/day)	V_E[f] (m^3/hour)
20−34													
Sleep	1	76	320	7.2	2.3	3.1	0.4	62	283	7.2	2.0	2.8	0.4
Light	1.5	76	320	14.5	7.0	9.4	0.7	62	283	14.5	6.2	8.3	0.6
Moderate	4	76	320	1.2	1.5	2.1	1.7	62	283	1.2	1.4	1.8	1.5
Hard	6	76	320	0.64	1.2	1.7	2.6	62	283	0.64	1.1	1.5	2.3
Very Hard	10	76	320	0.23	0.74	1.0	4.3	62	283	0.23	0.65	0.88	3.8
Totals				24	17	17				24	11	15	
35−49													
Sleep	1	81	314	7.1	2.2	3.0	0.4	67	242	7.1	1.7	2.3	0.3
Light	1.5	81	314	14.6	6.9	9.3	0.6	67	242	14.6	5.3	7.2	0.5
Moderate	4	81	314	1.4	1.8	2.4	1.7	67	242	1.4	1.4	1.8	1.3
Hard	6	81	314	0.59	1.1	1.5	2.5	67	242	0.59	0.9	1.2	2.0
Very Hard	10	81	314	0.29	0.91	1.2	4.2	67	242	0.29	0.70	0.95	3.2
Totals				24	13	17				24	9.9	13	
50−64													
Sleep	1	80	312	7.3	2.3	3.1	0.4	68	244	7.3	1.8	2.4	0.3
Light	1.5	80	312	14.9	7.0	9.4	0.6	68	244	14.9	5.4	7.4	0.5
Moderate	4	80	312	1.1	1.4	1.9	1.7	68	244	1.1	1.1	1.4	1.3
Hard	6	80	312	0.50	0.94	1.3	2.5	68	244	0.5	0.7	1.0	2.0
Very Hard	10	80	312	0.14	0.44	0.6	4.2	68	244	0.14	0.34	0.46	3.3
Totals				24	12	16				24	9.4	13	
65−74													
Sleep	1	75	256	7.3	1.9	2.5	0.3	67	221	7.3	1.6	2.2	0.3
Light	1.5	75	256	14.9	5.7	7.7	0.5	67	221	14.9	4.9	6.7	0.4
Moderate	4	75	256	1.1	1.1	1.5	1.4	67	221	1.1	1.0	1.3	1.2
Hard	6	75	256	0.5	0.8	1.0	2.1	67	221	0.5	0.7	0.9	1.8
Very Hard	10	75	256	0.14	0.36	0.48	3.5	67	221	0.14	0.31	0.42	3.0
Totals				24	9.8	13				24	8.5	11	

a Body weights were obtained from Najjar and Rowland (1987).
b The BMRs for the age/sex cohorts were calculated using the respective body weights and the BMR equations (see Table 6-46).
c Duration of activities were obtained from Sallis et al. (1985).
d Energy expenditure rate (*E*) was calculated by multiplying BMR (KJ/hour) × (MJ/1,000 KJ) × duration (hour/day) × MET.
e V_E (inhalation rate) was calculated by multiplying *E* (MJ/day) by *H* (0.05 m^3 oxygen/MJ) by VQ (27).
f V_E (m^3/hour) was calculated by multiplying BMR (KJ/hour) × (MJ/1,000 KJ) × MET × *H* (0.05 m^3 oxygen/MJ) × VQ (27).

Source: Layton (1993).

Table 6-49. Inhalation Rates for Short-Term Exposures

Sex/Age (years)	Body Weight (kg)[a]	BMR[b] (MJ/day)	Activity Type: Rest	Sedentary	Light	Moderate	Heavy
			MET (BMR Multiplier): 1	1.2	2[c]	4[d]	10[e]
			Inhalation Rate (m^3/minute)[f,g]				
Males							
0.5 to <3	14	3.40	3.2E−03	3.8E−03	6.3E−03	1.3E−02	–[h]
3 to <10	23	4.30	4.0E−03	4.8E−03	8.2E−03	1.6E−02	–[h]
10 to <18	53	6.70	6.3E−03	7.5E−03	1.3E−02	2.5E−02	6.3E−02
18 to <30	76	7.70	7.2E−03	8.7E−03	1.4E−02	2.9E−02	7.2E−02
30 to <60	80	7.50	7.0E−03	8.3E−03	1.4E−02	2.8E−02	7.0E−02
≥60	75	6.10	5.7E−03	6.8E−03	1.1E−02	2.3E−02	5.7E−02
Females							
0.5 to <3	11	2.60	2.4E−03	2.8E−03	4.8E−03	1.0E−02	–[h]
3 to <10	23	4.00	3.8E−03	4.5E−03	7.5E−03	1.5E−02	–[h]
10 to <18	50	5.70	5.3E−03	6.3E−03	1.1E−02	2.1E−02	5.3E−02
18 to <30	62	5.90	5.5E−03	6.7E−03	1.1E−02	2.2E−02	5.5E−02
30 to <60	68	5.80	5.3E−03	6.5E−03	1.1E−02	2.2E−02	5.4E−02
≥60	67	5.30	5.0E−03	6.0E−03	9.8E−03	2.0E−02	5.0E−02

[a] Body weights were based on average weights for age/sex cohorts of the U.S. population.

[b] The BMRs for the age/sex cohorts were calculated using the respective body weights and the BMR equations (see Table 6-46).

[c] Range = 1.5−2.5.

[d] Range = 3−5.

[e] Range = >5−20.

[f] The inhalation rate was calculated as *IR* = *BMR* (MJ/day) × *H* (0.05 L/KJ) × *MET* × *VQ* (27) × (day/1,440 minutes).

[g] Original data were presented in L/minute. Conversion to m^3/minute was obtained as follows: $\frac{m^3}{1000L} \times \frac{L}{min}$

[h] The maximum possible MET sustainable for more than 5 minutes does not reach 10 for females and males until ages 13 and 12, respectively. Therefore, an MET of 10 is not possible for this age category.

Source: Layton (1993).

Table 6-50. Distributions of Individual and Group Inhalation/Ventilation Rate (VR) for Outdoor Workers

		VR (m^3/hour)		
		Percentile		
Population Group and Subgroup[a]	Mean ± SD	1st	50th	99th
All Subjects (N[b] = 19)	1.68 ± 0.72	0.66	1.62	3.90
Job				
GCW[c]/Laborers (N = 5)	1.44 ± 0.66	0.48	1.32	3.66
Iron Workers (N = 3)	1.62 ± 0.66	0.60	1.56	3.24
Carpenters (N = 11)	1.86 ± 0.78	0.78	1.74	4.14
Site				
Medical Office Site (N = 7)	1.38 ± 0.66	0.60	1.20	3.72
Hospital Site (N = 12)	1.86 ± 0.78	0.72	1.80	3.96

[a] Each group or subgroup mean was calculated from individual means, not from pooled data.
[b] N = number of individuals performing specific jobs or number of individuals at survey sites.
[c] GCW = general construction worker.

Source: Linn et al. (1993).

Table 6-51. Individual Mean Inhalation Rate (m^3/hour) by Self-Estimated Breathing Rate or Job Activity Category for Outdoor Workers

	Self-Estimated Breathing Rate (m^3/hour)			Job Activity Category (m^3/hour)			
Population Group and Subgroup	Slow	Medium	Fast	Sit/Stand	Walk	Carry	Trade[a]
All Subjects (N = 19)	1.44	1.86	2.04	1.56	1.80	2.10	1.92
Job							
GCW[b]/Laborers (N = 5)	1.20	1.56	1.68	1.26	1.44	1.74	1.56
Iron Workers (N = 3)	1.38	1.86	2.10	1.62	1.74	1.98	1.92
Carpenters (N = 11)	1.62	2.04	2.28	1.62	1.92	2.28	2.04
Site							
Office Site (N = 12)	1.14	1.44	1.62	1.14	1.38	1.68	1.44
Hospital Site (N = 12)	1.62	2.16	2.40	1.80	2.04	2.34	2.16

[a] Trade = “Working at Trade” (i.e., tasks specific to the individual’s job classification).
[b] GCW = general construction worker.

Source: Linn et al. (1993).

Table 6-52. Mean, Median, and SD of Inhalation Rate According to Waking or Sleeping in 618 Infants and Children Grouped in Classes of Age

		Inhalation Rate (breaths/minute)			
		Waking		Sleeping	
Age (months)	*N*	Mean ± SD	Median	Mean ± SD	Median
<2	104	48.0 ± 9.1	47	39.8 ± 8.7	39
2 to <6	106	44.1 ± 9.9	42	33.4 ± 7.0	32
6 to <12	126	39.1 ± 8.5	38	29.6 ± 7.0	28
12 to <18	77	34.5 ± 5.8	34	27.2 ± 5.6	26
18 to <24	65	32.0 ± 4.8	32	25.3 ± 4.6	24
24 to <30	79	30.0 ± 6.2	30	23.1 ± 4.6	23
30 to 36	61	27.1 ± 4.1	28	21.5 ± 3.7	21

SD = Standard deviation.
N = Number of individuals.

Source: Rusconi et al. (1994).

Table 6-53. Distribution of Physiological Daily Inhalation Rate (PDIR) (m^3/day) Percentiles for Free-Living Underweight[a] Adolescents and Women Aged 11 to 55 Years During Pregnancy and Postpartum Weeks

Age Group (years)	Progression of the Reproductive Cycle		Number of Subjects[b] NExp or NSim	Physiological Daily Inhalation Rates[c] (m^3/day)								
					Percentile							
				Mean ± SD	5th	10th	25th	50th	75th	90th	95th	99th
11 to <23	Non-pregnant females		50	12.18 ± 2.08	8.76	9.52	10.78	12.18	13.58	14.84	15.60	17.02
	Pre-pregnancy	0 week	5,000	12.27 ± 1.95	9.35	9.74	10.79	12.18	13.72	14.63	15.48	16.90
	Pregnancy	9th week	5,000	17.83 ± 4.52	13.20	13.91	15.40	17.34	19.55	21.38	23.13	27.40
	Pregnancy	22nd week	5,000	17.98 ± 4.77	13.19	13.95	15.47	17.46	19.73	22.09	23.90	30.69
	Pregnancy	36th week	5,000	18.68 ± 4.73	13.44	14.25	15.96	17.88	20.24	23.01	25.59	34.45
	Postpartum	6th week	5,000	20.39 ± 2.69	16.31	17.02	18.47	20.31	22.22	23.79	24.82	26.62
	Postpartum	27th week	5,000	20.21 ± 2.66	16.17	16.88	18.31	20.14	22.02	23.58	24.61	26.39
23 to <30	Non-pregnant females		17	13.93 ± 2.27	10.20	11.02	12.40	13.93	13.93	16.83	17.65	19.20
	Pre-pregnancy	0 week	5,000	13.91 ± 2.17	11.41	11.50	12.08	13.92	15.32	16.01	17.81	19.97
	Pregnancy	9th week	5,000	20.03 ± 5.01	15.83	16.17	17.08	19.75	21.60	23.76	26.94	34.21
	Pregnancy	22nd week	5,000	20.15 ± 4.24	15.81	16.16	17.07	19.80	21.67	24.49	27.46	32.69
	Pregnancy	36th week	5,000	20.91 ± 5.37	15.97	16.37	17.56	20.29	22.31	26.42	28.95	38.26
	Postpartum	6th week	5,000	22.45 ± 2.91	18.70	19.15	20.14	22.23	24.15	25.65	27.68	30.57
	Postpartum	27th week	5,000	22.25 ± 2.89	18.53	18.98	19.96	22.04	23.94	25.42	27.44	30.30
30 to 55	Non-pregnant females		14	12.89 ± 1.40	10.58	11.09	11.94	12.89	12.89	14.69	15.20	16.16
	Pre-pregnancy	0 week	5,000	12.91 ± 1.36	10.85	11.28	11.99	12.49	13.98	14.99	15.13	15.18
	Pregnancy	9th week	5,000	18.68 ± 3.95	15.33	15.93	16.79	18.05	20.22	21.39	22.69	27.38
	Pregnancy	22nd week	5,000	18.84 ± 4.08	15.30	15.93	16.80	18.07	20.23	21.52	23.20	30.80
	Pregnancy	36th week	5,000	19.60 ± 4.66	15.54	16.14	17.03	18.73	20.74	23.04	25.58	34.26
	Postpartum	6th week	5,000	21.19 ± 1.96	18.30	18.86	19.79	20.92	22.58	23.98	24.53	25.28
	Postpartum	27th week	5,000	21.01 ± 1.94	18.14	18.69	19.62	20.74	22.39	23.77	24.31	25.07

[a] Underweight females are defined as those having a body mass index lower than 19.8 kg/m^2 in pre-pregnancy.
[b] NExp = number of experimental non-pregnant and non-lactating females; NSim = number of simulated females.
[c] Resulting total energy requirements (TDERs) from the integration of energetic measurements in underweight non-pregnant and non-lactating females with those during pregnancy and lactation by Monte Carlo simulations were converted into physiological daily inhalation rates by the following equation: $TDER \times H \times (V_E/VO_2) \times 10^{-3}$. *TDER* = total energy requirement (*ECG + TDEE*). *ECG* = stored daily energy cost for growth; *TDEE* = total daily energy.

SD = Standard deviation.

Source: Brochu et al. (2006a).

Table 6-54. Distribution of Physiological Daily Inhalation Rate (PDIR) (m^3/day) Percentiles for Free-Living Normal-Weight[a] Adolescents and Women Aged 11 to 55 Years During Pregnancy and Postpartum Weeks

Age Group (years)	Progression of the Reproductive Cycle		Number of Subjects[b] NExp or NSim	Physiological Daily Inhalation Rates[c] (m^3/day)								
					Percentile							
				Mean ± SD	5th	10th	25th	50th	75th	90th	95th	99th
11 to <23	Non-pregnant females		57	14.55 ± 2.70	10.11	11.09	12.73	14.55	16.37	18.01	18.99	20.83
	Pre-pregnancy	0 week	5,000	14.55 ± 2.69	9.71	10.83	13.29	14.78	15.89	17.34	18.71	20.91
	Pregnancy	9th week	5,000	19.99 ± 3.89	13.32	14.84	18.32	20.26	21.86	23.86	25.89	28.75
	Pregnancy	22nd week	5,000	22.59 ± 4.83	15.35	17.09	20.06	22.27	24.69	28.25	30.75	35.88
	Pregnancy	36th week	5,000	23.27 ± 4.63	16.01	17.76	20.69	23.10	25.55	28.77	31.07	35.65
	Postpartum	6th week	5,000	23.28 ± 3.60	16.91	18.36	21.40	23.56	25.24	27.17	28.98	31.80
	Postpartum	27th week	5,000	23.08 ± 3.56	16.76	18.20	21.21	23.36	25.02	26.93	28.73	31.52
23 to <30	Non-pregnant females		54	13.59 ± 2.23	9.92	10.73	12.09	13.59	15.09	16.45	17.26	18.78
	Pre-pregnancy	0 week	5,000	13.66 ± 2.29	10.19	10.64	12.12	13.73	14.90	16.49	17.87	19.09
	Pregnancy	9th week	5,000	19.00 ± 9.98	13.92	14.55	16.55	18.76	20.49	22.80	24.49	27.04
	Pregnancy	22nd week	5,000	21.36 ± 4.36	15.54	16.70	18.63	20.89	23.58	26.59	28.43	33.98
	Pregnancy	36th week	5,000	22.14 ± 4.13	16.21	17.34	19.35	21.69	24.55	27.59	29.27	32.77
	Postpartum	6th week	5,000	22.15 ± 30.5	17.37	18.26	20.11	22.11	23.96	26.21	27.53	29.21
	Postpartum	27th week	5,000	21.96 ± 3.02	17.22	18.10	19.93	21.91	23.75	25.98	27.29	28.96
30 to 55	Non-pregnant females		61	13.82 ± 1.91	10.67	11.37	12.53	13.82	15.12	16.28	16.97	18.28
	Pre-pregnancy	0 week	5,000	13.79 ± 1.83	11.07	11.48	12.54	13.61	14.91	16.40	17.02	18.32
	Pregnancy	9th week	5,000	19.02 ± 3.81	15.18	15.74	17.14	18.63	20.46	22.45	23.38	27.39
	Pregnancy	22nd week	5,000	21.53 ± 4.06	16.71	17.56	19.01	20.85	23.45	26.03	28.30	33.44
	Pregnancy	36th week	5,000	22.20 ± 3.68	17.45	18.19	19.69	21.73	24.16	26.78	28.53	32.75
	Postpartum	6th week	5,000	22.31 ± 2.50	18.72	19.35	20.58	22.09	23.84	25.70	26.70	28.39
	Postpartum	27th week	5,000	22.12 ± 2.48	18.55	19.18	20.40	21.90	23.64	25.47	26.47	28.14

[a] Normal-weight females are defined as those having a body mass index varying between 19.8 and 26 kg/m^2 in pre-pregnancy.
[b] NExp = number of experimental non-pregnant and non-lactating females; NSim = number of simulated females.
[c] Resulting TDERs from the integration of energetic measurements in underweight non-pregnant and non-lactating females with those during pregnancy and lactation by Monte Carlo simulations were converted into physiological daily inhalation rates by the following equation: $TDER \times H \times (V_E/VO_2) \times 10^{-3}$. *TDER* = total energy requirement (*ECG* + *TDEE*). *ECG* = stored daily energy cost for growth; *TDEE* = total daily energy.
SD = Standard deviation.
Source: Brochu et al. (2006a).

Table 6-55. Distribution of Physiological Daily Inhalation Rate (PDIR) (m^3/day) Percentiles for Free-Living Overweight/Obese[a] Adolescents and Women Aged 11 to 55 Years During Pregnancy and Postpartum Weeks

Age Group (years)	Progression of the Reproductive Cycle		Number of Subjects[b] NExp or NSim	Physiological Daily Inhalation Rates[c] (m^3/day)								
					Percentile							
				Mean ± SD	5th	10th	25th	50th	75th	90th	95th	99th
11 to <23	Non-pregnant females		15	16.62 ± 2.91	11.82	12.88	14.65	16.62	18.58	20.35	21.41	23.39
	Pre-pregnancy	0 week	5,000	16.64 ± 2.81	10.21	12.13	15.52	17.22	18.52	19.68	20.06	20.16
	Pregnancy	9th week	5,000	25.51 ± 6.48	16.11	19.09	23.04	25.38	27.85	30.62	33.32	41.61
	Pregnancy	22nd week	5,000	26.10 ± 6.96	16.38	19.29	23.12	25.65	28.17	31.56	34.93	45.94
	Pregnancy	36th week	5,000	25.71 ± 8.09	15.67	18.78	22.73	25.23	27.84	31.14	34.95	46.76
	Postpartum	6th week	5,000	25.93 ± 3.70	17.94	20.12	24.52	26.61	28.38	29.87	30.53	31.27
	Postpartum	27th week	5,000	25.71 ± 3.67	17.79	19.94	24.30	26.38	28.13	29.61	30.26	31.00
23 to <30	Non-pregnant females		25	15.45 ± 2.32	11.63	12.47	13.88	15.45	17.02	18.43	19.27	20.86
	Pre-pregnancy	0 week	5,000	15.47 ± 2.27	11.94	13.12	14.36	15.50	16.86	17.96	19.46	20.41
	Pregnancy	9th week	5,000	23.93 ± 5.94	17.75	19.13	21.08	23.22	25.62	29.09	31.77	40.74
	Pregnancy	22nd week	5,000	24.44 ± 6.24	18.06	19.45	21.32	23.51	26.44	29.92	33.49	44.56
	Pregnancy	36th week	5,000	24.15 ± 6.82	17.60	19.00	20.91	23.05	26.02	30.04	34.18	47.31
	Postpartum	6th week	5,000	24.47 ± 3.04	19.31	21.07	22.80	24.45	26.16	27.93	29.43	31.08
	Postpartum	27th week	5,000	24.25 ± 3.02	19.14	20.88	22.60	24.23	25.93	27.68	29.17	30.81
30 to 55	Non-pregnant females		64	15.87 ± 2.52	11.72	12.63	14.17	15.87	17.57	19.10	20.01	21.73
	Pre-pregnancy	0 week	5,000	15.83 ± 2.46	11.92	12.79	14.30	15.79	17.19	18.78	19.47	22.03
	Pregnancy	9th week	5,000	24.47 ± 5.68	17.87	19.17	21.38	23.77	26.37	29.77	33.08	41.49
	Pregnancy	22nd week	5,000	25.02 ± 6.65	18.13	19.41	21.44	23.92	26.93	30.98	35.01	46.88
	Pregnancy	36th week	5,000	24.46 ± 6.24	17.67	18.83	20.92	23.40	26.37	30.32	34.27	45.08
	Postpartum	6th week	5,000	24.91 ± 3.28	19.82	20.92	22.82	24.91	26.81	28.70	29.75	32.94
	Postpartum	27th week	5,000	24.70 ± 3.25	19.65	20.74	22.63	24.69	26.58	28.45	29.50	32.65

[a] Overweight/obese females are defined as those having a body mass index higher than 26 kg/m^2 in pre-pregnancy.
[b] NExp = number of experimental non-pregnant and non-lactating females; NSim = number of simulated females.
[c] Resulting TDERs from the integration of energetic measurements in underweight non-pregnant and non-lactating females with those during pregnancy and lactation by Monte Carlo simulations were converted into physiological daily inhalation rates by the following equation: $TDER \times H \times (V_E/VO_2) \times 10^{-3}$. *TDER* = total energy requirement (*ECG* + *TDEE*). *ECG* = stored daily energy cost for growth; *TDEE* = total daily energy.
SD = Standard deviation.
Source: Brochu et al. (2006a).

Table 6-56. Distribution of Physiological Daily Inhalation Rate (PDIR) (m^3/kg-day) Percentiles for Free-Living Underweight[a] Adolescents and Women Aged 11 to 55 Years During Pregnancy and Postpartum Weeks

Age Group (years)	Progression of the Reproductive Cycle		Number of Subjects[b] NExp or NSim	Physiological Daily Inhalation Rates[c] (m^3/kg-day)								
					Percentile							
				Mean ± SD	5th	10th	25th	50th	75th	90th	95th	99th
11 to <23	Non-pregnant females		50	0.277 ± 0.046	0.201	0.218	0.246	0.277	0.277	0.335	0.352	0.383
	Pre-pregnancy	0 week	5,000	0.276 ± 0.045	0.209	0.218	0.238	0.277	0.313	0.337	0.345	0.368
	Pregnancy	9th week	5,000	0.385 ± 0.110	0.278	0.291	0.327	0.377	0.428	0.474	0.504	0.622
	Pregnancy	22nd week	5,000	0.343 ± 0.093	0.246	0.259	0.291	0.335	0.378	0.419	0.455	0.602
	Pregnancy	36th week	5,000	0.323 ± 0.083	0.230	0.243	0.274	0.314	0.357	0.404	0.452	0.575
	Postpartum	6th week	5,000	0.368 ± 0.058	0.321	0.337	0.370	0.414	0.467	0.517	0.548	0.596
	Postpartum	27th week	5,000	0.383 ± 0.064	0.329	0.348	0.383	0.433	0.491	0.549	0.584	0.647
23 to <30	Non-pregnant females		17	0.264 ± 0.047	0.186	0.203	0.232	0.264	0.264	0.325	0.342	0.374
	Pre-pregnancy	0 week	5,000	0.264 ± 0.046	0.206	0.212	0.228	0.257	0.284	0.342	0.361	0.362
	Pregnancy	9th week	5,000	0.366 ± 0.098	0.277	0.287	0.311	0.351	0.400	0.468	0.501	0.591
	Pregnancy	22nd week	5,000	0.332 ± 0.076	0.250	0.260	0.282	0.318	0.362	0.421	0.452	0.532
	Pregnancy	36th week	5,000	0.317 ± 0.086	0.233	0.242	0.266	0.301	0.346	0.402	0.439	0.582
	Postpartum	6th week	5,000	0.352 ± 0.056	0.307	0.320	0.348	0.385	0.431	0.486	0.518	0.573
	Postpartum	27th week	5,000	0.364 ± 0.061	0.316	0.330	0.357	0.397	0.449	0.508	0.545	0.606
30 to 55	Non-pregnant females		14	0.249 ± 0.027	0.204	0.214	0.231	0.249	0.249	0.283	0.293	0.312
	Pre-pregnancy	0 week	5,000	0.249 ± 0.026	0.208	0.220	0.232	0.242	0.268	0.286	0.294	0.299
	Pregnancy	9th week	5,000	0.347 ± 0.075	0.279	0.291	0.311	0.337	0.370	0.405	0.431	0.529
	Pregnancy	22nd week	5,000	0.315 ± 0.071	0.252	0.262	0.280	0.305	0.335	0.368	0.401	0.529
	Pregnancy	36th week	5,000	0.301 ± 0.074	0.233	0.243	0.260	0.287	0.321	0.360	0.404	0.529
	Postpartum	6th week	5,000	0.337 ± 0.038	0.312	0.326	0.347	0.376	0.408	0.439	0.457	0.489
	Postpartum	27th week	5,000	0.349 ± 0.042	0.320	0.333	0.357	0.389	0.425	0.462	0.483	0.518

[a] Underweight females are defined as those having a body mass index lower than 19.8 kg/m^2 in pre-pregnancy.
[b] NExp = number of experimental non-pregnant and non-lactating females; NSim = number of simulated females.
[c] Resulting TDERs from the integration of energetic and weight measurements in normal-weight non-pregnant and non-lactating females with those during pregnancy and lactation by Monte Carlo simulations were converted into physiological daily inhalation rates by the following equation: $TDER \times H \times (V_E/VC > 2) \times 10^{-3}$. $TDER$ = total energy requirement ($ECG + TDEE$). ECG = stored daily energy cost for growth; $TDEE$ = total daily energy expenditure.
SD = Standard deviation.
Source: Brochu et al. (2006a).

Table 6-57. Distribution of Physiological Daily Inhalation Rate (PDIR) (m^3/kg-day) Percentiles for Free-Living Normal-Weight[a] and Women Aged 11 to 55 Years During Pregnancy and Postpartum Weeks

Age Group (years)	Progression of the Reproductive Cycle		Number of Subjects[b] NExp or NSim	Physiological Daily Inhalation Rates[c] (m^3/kg-day)								
					Percentile							
				Mean ± SD	5th	10th	25th	50th	75th	90th	95th	99th
11 to <23	Non-pregnant females		15	0.252 ± 0.051	0.168	0.186	0.217	0.252	0.286	0.317	0.336	0.370
	Pre-pregnancy	0 week	5,000	0.252 ± 0.051	0.169	0.189	0.218	0.246	0.282	0.324	0.339	0.361
	Pregnancy	9th week	5,000	0.344 ± 0.074	0.232	0.259	0.297	0.336	0.388	0.440	0.468	0.518
	Pregnancy	22nd week	5,000	0.360 ± 0.085	0.243	0.268	0.304	0.349	0.406	0.462	0.500	0.594
	Pregnancy	36th week	5,000	0.329 ± 0.072	0.225	0.247	0.281	0.323	0.372	0.422	0.453	0.517
	Postpartum	6th week	5,000	0.342 ± 0.062	0.272	0.292	0.327	0.369	0.418	0.469	0.499	0.544
	Postpartum	27th week	5,000	0.352 ± 0.067	0.279	0.298	0.334	0.380	0.433	0.490	0.527	0.580
23 to <30	Non-pregnant females		54	0.221 ± 0.035	0.164	0.176	0.197	0.221	0.244	0.265	0.278	0.301
	Pre-pregnancy	0 week	5,000	0.222 ± 0.035	0.174	0.181	0.199	0.218	0.242	0.269	0.285	0.317
	Pregnancy	9th week	5,000	0.308 ± 0.189	0.233	0.243	0.269	0.298	0.333	0.371	0.395	0.458
	Pregnancy	22nd week	5,000	0.321 ± 0.067	0.239	0.252	0.277	0.310	0.351	0.399	0.433	0.521
	Pregnancy	36th week	5,000	0.297 ± 0.056	0.220	0.233	0.258	0.289	0.328	0.369	0.399	0.448
	Postpartum	6th week	5,000	0.309 ± 0.045	0.265	0.278	0.302	0.333	0.368	0.402	0.425	0.464
	Postpartum	27th week	5,000	0.317 ± 0.049	0.269	0.283	0.309	0.342	0.380	0.416	0.441	0.490
30 to 55	Non-pregnant females		61	0.229 ± 0.035	0.171	0.184	0.206	0.229	0.253	0.274	0.287	0.311
	Pre-pregnancy	0 week	5,000	0.229 ± 0.035	0.174	0.187	0.202	0.229	0.253	0.275	0.287	0.302
	Pregnancy	9th week	5,000	0.314 ± 0.069	0.237	0.252	0.276	0.309	0.346	0.382	0.400	0.443
	Pregnancy	22nd week	5,000	0.330 ± 0.069	0.242	0.257	0.285	0.321	0.365	0.409	0.439	0.522
	Pregnancy	36th week	5,000	0.303 ± 0.057	0.225	0.238	0.264	0.297	0.336	0.373	0.401	0.461
	Postpartum	6th week	5,000	0.316 ± 0.046	0.267	0.280	0.307	0.343	0.382	0.416	0.434	0.467
	Postpartum	27th week	5,000	0.325 ± 0.050	0.272	0.285	0.314	0.352	0.394	0.432	0.453	0.491

a Normal-weight females are defined as those having a body mass index varying between 19.8 and 26 kg/m^2 in pre-pregnancy.
b NExp = number of experimental non-pregnant and non-lactating females; NSim = number of simulated females.
c Resulting TDERs from the integration of energetic and weight measurements in normal-weight non-pregnant and non-lactating females with those during pregnancy and lactation by Monte Carlo simulations were converted into physiological daily inhalation rates by the following equation: $TDER \times H \times (V_E/VC > 2) \times 10^{-3}$. *TDER* = total energy requirement (*ECG* + *TDEE*). *ECG* = stored daily energy cost for growth; *TDEE* = total daily energy expenditure.
SD = Standard deviation.
Source: Brochu et al. (2006a).

Table 6-58. Distribution of Physiological Daily Inhalation Rate (PDIR) (m^3/kg-day) Percentiles for Free-Living Overweight/Obese[a] Adolescents and Women Aged 11 to 55 Years During Pregnancy and Postpartum Weeks

Age Group (years)	Progression of the Reproductive Cycle		Number of Subjects[b] NExp or NSim	Physiological Daily Inhalation Rates[c] (m^3/kg-day)								
					Percentile							
				Mean ± SD	5th	10th	25th	50th	75th	90th	95th	99th
11 to <23	Non-pregnant females		15	0.206 ± 0.033	0.151	0.163	0.184	0.206	0.229	0.249	0.261	0.284
	Pre-pregnancy	0 week	5,000	0.207 ± 0.032	0.146	0.153	0.188	0.214	0.227	0.240	0.253	0.259
	Pregnancy	9th week	5,000	0.302 ± 0.075	0.205	0.223	0.263	0.298	0.329	0.368	0.401	0.515
	Pregnancy	22nd week	5,000	0.287 ± 0.079	0.191	0.206	0.246	0.279	0.314	0.357	0.391	0.512
	Pregnancy	36th week	5,000	0.270 ± 0.090	0.179	0.193	0.225	0.259	0.296	0.337	0.377	0.521
	Postpartum	6th week	5,000	0.280 ± 0.050	0.213	0.230	0.266	0.301	0.337	0.372	0.395	0.444
	Postpartum	27th week	5,000	0.285 ± 0.053	0.214	0.233	0.269	0.307	0.344	0.381	0.409	0.464
23 to <30	Non-pregnant females		54	0.186 ± 0.025	0.144	0.153	0.169	0.186	0.203	0.218	0.227	0.244
	Pre-pregnancy	0 week	5,000	0.186 ± 0.025	0.143	0.155	0.172	0.183	0.201	0.222	0.233	0.236
	Pregnancy	9th week	5,000	0.274 ± 0.068	0.203	0.217	0.238	0.263	0.298	0.337	0.374	0.476
	Pregnancy	22nd week	5,000	0.261 ± 0.069	0.193	0.205	0.224	0.248	0.283	0.323	0.360	0.466
	Pregnancy	36th week	5,000	0.245 ± 0.074	0.175	0.185	0.205	0.231	0.268	0.314	0.360	0.498
	Postpartum	6th week	5,000	0.256 ± 0.042	0.205	0.217	0.241	0.271	0.304	0.338	0.360	0.406
	Postpartum	27th week	5,000	0.260 ± 0.046	0.209	0.222	0.246	0.277	0.311	0.349	0.372	0.426
30 to 55	Non-pregnant females		61	0.184 ± 0.031	0.132	0.144	0.163	0.184	0.205	0.224	0.235	0.257
	Pre-pregnancy	0 week	5,000	0.184 ± 0.031	0.127	0.141	0.166	0.185	0.205	0.221	0.226	0.246
	Pregnancy	9th week	5,000	0.272 ± 0.068	0.184	0.203	0.234	0.263	0.299	0.343	0.378	0.465
	Pregnancy	22nd week	5,000	0.259 ± 0.071	0.176	0.194	0.222	0.249	0.282	0.322	0.363	0.490
	Pregnancy	36th week	5,000	0.242 ± 0.068	0.162	0.177	0.201	0.230	0.265	0.313	0.351	0.455
	Postpartum	6th week	5,000	0.253 ± 0.048	0.188	0.205	0.237	0.270	0.305	0.340	0.364	0.404
	Postpartum	27th week	5,000	0.257 ± 0.051	0.191	0.208	0.239	0.273	0.310	0.348	0.374	0.430

a Overweight/obese females are defined as those having a body mass index higher than 26 kg/m^2 in pre-pregnancy.
b NExp = number of experimental non-pregnant and non-lactating females; NSim = number of simulated females.
c Resulting TDERs from the integration of energetic and weight measurements in normal-weight non-pregnant and non-lactating females with those during pregnancy and lactation by Monte Carlo simulations were converted into physiological daily inhalation rates by the following equation: $TDER \times H \times (V_E/VC > 2) \times 10^{-3}$. *TDER* = total energy requirement (*ECG* + *TDEE*). *ECG* = stored daily energy cost for growth; *TDEE* = total daily energy expenditure.
SD = Standard deviation.
Source: Brochu et al. (2006a).

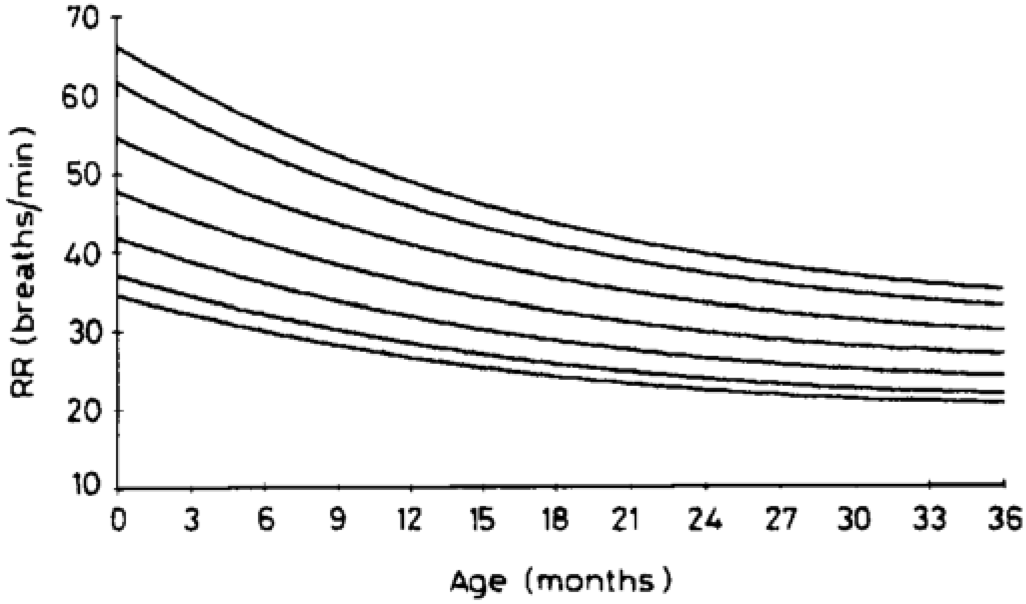

Figure 6-1. **5th, 10th, 25th, 50th, 75th, 90th, and 95th Smoothed Centiles by Age in Awake Subjects.**
RR = respiratory rate.
Source: Rusconi et al. (1994).

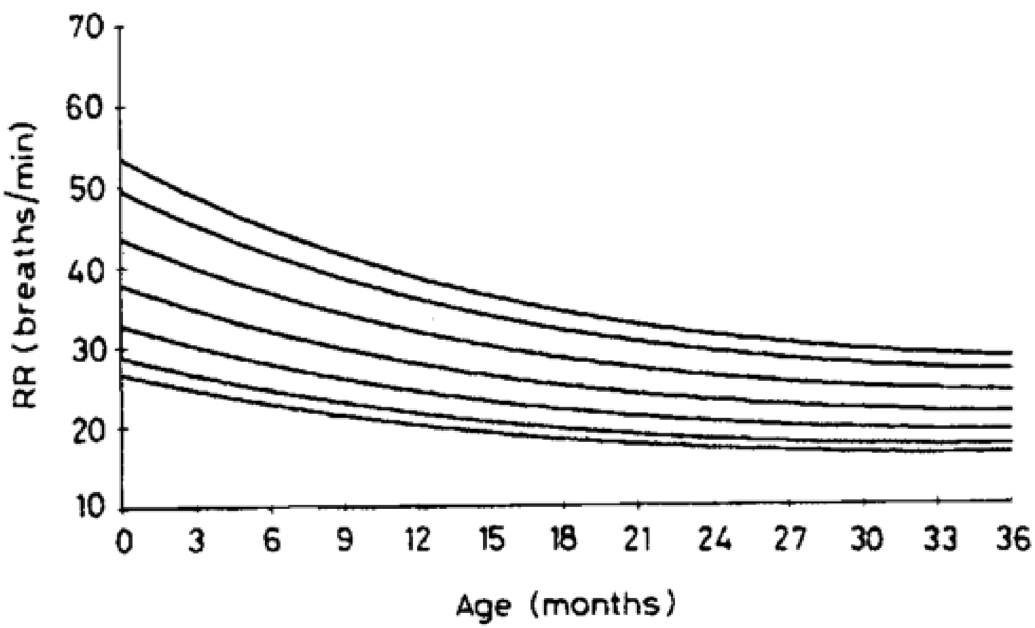

Figure 6-2. **5th, 10th, 25th, 50th, 75th, 90th, and 95th Smoothed Centiles by Age in Asleep Subjects.**
RR = respiratory rate.
Source: Rusconi et al. (1994).