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PREFACE

The National Center for Environmental Assessment (NCEA) of EPA's Office of Research and Development (ORD) has prepared this handbook to address factors commonly used in exposure assessments. This handbook was first published in 1989 in response to requests from many EPA Program and Regional offices for additional guidance on how to select values for exposure factors.

Several events sparked the efforts to revise the Exposure Factors Handbook. First, since its publication in 1989, new data have become available. Second, the Risk Assessment Council issued a memorandum titled, "Guidance on Risk Characterization for Risk Managers and Risk Assessors," dated February 26, 1992, which emphasized the use of multiple descriptors of risk (i.e., measures of central tendency such as average or mean, or high end), and characterization of individual risk, population risk, important subpopulations. A new document was issued titled "Guidance for Risk Characterization," dated February 1995. This document is an update of the guidance issued with the 1992 policy. Third, EPA published the revised Guidelines for Exposure Assessment in 1992.

As part of the efforts to revise the handbook, the EPA Risk Assessment Forum sponsored a two-day peer involvement workshop which was conducted during the summer of 1993. The workshop was attended by 57 scientists from academia, consulting firms, private industry, the States, and other Federal agencies. The purpose of the workshop was to identify new data sources, to discuss adequacy of the data and the feasibility of developing statistical distributions and to establish priorities.

As a result of the peer involvement workshop, three new chapters were added to the handbook. These chapters are: Consumer Product Use, Residential Building Characteristics, and Intake of Grains. This document also provides a summary of the available data on consumption of drinking water; consumption of fruits, vegetables, beef, dairy products, grain products, and fish; breast milk intake; soil ingestion; inhalation rates; skin surface area; soil adherence; lifetime; activity patterns; and body weight.

A new draft handbook that incorporated comments from the 1993 workshop was published for peer review in June 1995. A peer review workshop was held in July 1995 to discuss comments on the draft handbook. A new draft of the handbook that addressed comments from the 1995 peer review workshop was submitted to the Science Advisory Board (SAB) for review in August 1996. An SAB workshop meeting was held December 19-20, 1996, to discuss the comments of the SAB reviewers. Comments from the SAB review have been incorporated into the current handbook.

FOREWORD

The National Center for Environmental Assessment (NCEA) of EPA's Office of Research and Development (ORD) has five main functions: (1) providing risk assessment research, methods, and guidelines; (2) performing health and ecological assessments; (3) developing, maintaining, and transferring risk assessment information and training; (4) helping ORD set research priorities; and (5) developing and maintaining resource support systems for NCEA. The activities under each of these functions are supported by and respond to the needs of the various program offices. In relation to the first function, NCEA sponsors projects aimed at developing or refining techniques used in exposure assessments.

This handbook was first published in 1989 to provide statistical data on the various factors used in assessing exposure. This revised version of the handbook provides the up-to-date data on these exposure factors. The recommended values are based solely on our 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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In addition, the National Exposure Research Laboratory (NERL) of the Office of Research and Development of EPA made an important contribution to this handbook by conducting additional analyses of the National Human Activity Pattern Survey (NHAPS) data. EPA input to the NHAPS data analysis came from Karen A. Hammerstrom and Jacqueline Moya from NCEA-Washington Office; William C. Nelson from NERL-RTP, and Stephen C. Hern, Joseph V. Behar (retired), and William H. Englemann from NERL-Las Vegas.

The EPA Office of Water made an important contribution by conducting an analysis of the USDA Continuing Survey of Food Intakes by Individual (CSFII) data. They provided fish intake rates for the general population. The analysis was conducted under the direction of Helen Jacobs from the Office of Water.

1. INTRODUCTION

1.1. PURPOSE

The purpose of the Exposure Factors Handbook is to: (1) summarize data on human behaviors and characteristics which affect exposure to environmental contaminants, and (2) recommend values to use for these factors. These recommendations are not legally binding on any EPA program and should be interpreted as suggestions which program offices or individual exposure assessors can consider and modify as needed. Most of these factors are best quantified on a site or situation-specific basis. The handbook has strived to include full discussions of the issues which assessors should consider in deciding how to use these data and recommendations. The handbook is intended to serve as a support document to EPA's Guidelines for Exposure Assessment (U.S. EPA, 1992a). The Guidelines were developed to promote consistency among the various exposure assessment activities that are carried out by the various EPA program offices. This handbook assists in this goal by providing a consistent set of exposure factors to calculate dose.

1.2. INTENDED AUDIENCE

The Exposure Factors Handbook is addressed to exposure assessors inside the Agency as well as outside, who need to obtain data on standard factors needed to calculate human exposure to toxic chemicals.

Purpose

- Summarize data on human behaviors and characteristics affecting exposure
- Recommend exposure factor values

1.3. BACKGROUND

This handbook is the update of an earlier version prepared in 1989. Revisions have been made in the following areas:

- addition of drinking water rates for children;
- changes in soil ingestion rates for children;
- addition of soil ingestion rates for adults;
- addition of tapwater consumption for adults and children;
- addition of mean daily intake of food class and subclass by region, age and per capita rates;
- addition of mean moisture content of selected fruits, vegetables, grains, fish, meat, and dairy products;
- addition of food intake by class in dry weight per kg of body weight per day;
- update of homegrown food intake;
- expansion of data in the dermal chapter;
- update of fish intake data;
- expansion of data for time spent at residence;
- update of body weight data;
- addition of body weight data for infants;
- update of population mobility data;
- addition of new data for average time spent in different locations and various microenvironments;
- addition of data for occupational mobility;
- addition of breast milk ingestion;
- addition of consumer product use; and
- addition of reference residence factors.

Variation Among Studies

This handbook is a compilation of available data from a variety of different sources. 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 populations. Within the constraint of presenting the original material as accurately as possible, EPA has made an effort to present discussions and results in a consistent manner. Further, 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.

1.3.1. Selection of Studies for the Handbook

Information in this handbook has been summarized from studies documented in the scientific literature and

other available sources. Studies were chosen that were seen as useful and appropriate for estimating exposure factors. The handbook contains summaries of selected studies published through August 30, 1997.

General Considerations

Many scientific studies were reviewed for possible inclusion in this handbook. Studies were selected based on the following considerations:

- Level of peer review: Studies were selected predominantly from the peer-reviewed literature and final government reports. Internal or interim reports were therefore avoided.

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

- Reproducibility: Studies were sought that contained sufficient information so that methods could be reproduced, or at least so the details of the author's work could be accessed and evaluated.

- Focus on exposure factor of interest: Studies were chosen 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.

- Data pertinent to the U.S.: Studies were selected that addressed the U.S. population. Data from populations outside the U.S. were sometimes included if behavioral patterns and other characteristics of exposure were similar.

- Primary data: Studies were deemed preferable if based on primary data, but studies based on secondary sources were also included where they offered an original analysis. For example, the handbook cites studies of food consumption based on original data collected by the USDA National Food Consumption Survey.

- Current information: Studies were chosen only if they were sufficiently recent to represent current exposure conditions. This is an important consideration for those factors that change with time.

- 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.

- Validity of approach: Studies utilizing experimental procedures or approaches that more likely or closely capture the desired measurement were selected. In general, 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 rely 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.

- Representativeness of the population: Studies seeking to characterize the national population, a particular region, or sub-population 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.

- Variability in the population: Studies were sought that characterized any variability within populations.

- 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 over or under estimate of the parameter) was either stated or apparent from the study design.

- Minimal (or defined) uncertainty in the data: Studies were sought with minimal uncertainty in the data, which was judged by evaluating all the considerations listed above. At least, studies were preferred that identified uncertainties, such as those due to inherent variability in environmental and exposure-related parameters or possible measurement error. Studies that documented Quality Assurance/Quality Control measures were preferable.

Key versus relevant studies

Certain studies described in this handbook are designated as "key," that is, the most useful for deriving exposure factors. The recommended values for most exposure factors are based on the results of the key studies. Other studies are designated "relevant," meaning applicable or pertinent, but not necessarily the most important. This distinction was made on the strength of the attributes listed in the "General Considerations." For example, in Chapter 14 of Volume III, one set of studies is deemed to best address the attributes listed and is designated as "key." Other applicable studies, including foreign data, believed to have value to handbook users, but having fewer attributes, are designated "relevant."

Key vs. Relevant Studies

- Key studies used to derive recommendations
- Relevant studies included to provide

1.3.2. Using the Handbook in an Exposure Assessment

Some of the steps for performing an exposure assessment are (1) determining the pathways of exposure, (2) identifying the environmental media which transports the contaminant, (3) determining the contaminant concentration, (4) determining the exposure time, frequency, and duration, and (5) identifying the exposed population. Many of the issues related to characterizing exposure from selected exposure pathways have been addressed in a number of existing EPA guidance documents. These include, but are not limited to the following:

- Guidelines for Exposure Assessment (U.S. EPA 1992a);
- Dermal Exposure Assessment: Principles and Applications (U.S. EPA 1992b);
- Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions (U.S. EPA, 1990);
- Risk Assessment Guidance for Superfund (U.S. EPA, 1989);
- Estimating Exposures to Dioxin-Like Compounds (U.S. EPA, 1994);
- Superfund Exposure Assessment Manual (U.S. EPA, 1988a);
- Selection Criteria for Mathematical Models Used in Exposure Assessments (U.S. EPA 1988b);
- Selection Criteria for Mathematical Models Used in Exposure Assessments (U.S. EPA 1987);
- Standard Scenarios for Estimating Exposure to Chemical Substances During Use of Consumer Products (U.S. EPA 1986a);
- Pesticide Assessment Guidelines, Subdivisions K and U (U.S. EPA, 1984, 1986b); and
- Methods for Assessing Exposure to Chemical Substances, Volumes 1-13 (U.S. EPA, 1983-1989).

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

In addition to the references listed above, this handbook discusses the recommendations provided by the American Industrial Health Council (AIHC) - Exposure Factors Sourcebook (May 1994) for some of the major exposure factors. The AIHC Sourcebook summarizes and evaluates statistical data for various exposure factors used in risk assessments. Probability distributions for

specific exposure factors were derived from the available scientific literature using @Risk simulation software. Each factor is described by a specific term, such as lognormal, normal, cumulative type, or triangular. Other distributions included Weibull, beta logistic, and gamma. Unlike this handbook, however, the Sourcebook does not provide a description and evaluation of every study available on each exposure factor.

Most of the data presented in this handbook are derived from studies that targeted (1) the general population (e.g., USDA food consumptin surveys); and (2) a sample population from a specific area or group (e.g., Calabrese's et al. (1989) soil ingestion study using children from the Amherst, Massachusetts, area). Due to unique activity patterns, preferences, practices and biological differences, various segments of the population may experience exposures that are different from those of the general population, which, in many cases, may be greater. It is necessary for risk or exposure assessors characterizing a diverse population, to identify and enumerate certain groups within the general population who are at risk for greater contaminant exposures or exhibit a heightened sensitivity to particular chemicals. For further guidance on addressing susceptible populations, it is recommended to consult the EPA, National Center for Environmental Assessment document *Socio-demographic Data Used for Identifying Potentially Highly Exposed Subpopulations* (to be released as a final document in the Fall of 1997).

Most users of the handbook will be preparing estimates of exposure which are to be combined with dose-response factors to estimate risk. Some of the exposure factors (e.g., life time, body weight) presented in this document are also used in generating dose-response relationships. In order to develop risk estimates properly, assessors must use dose-response relationships in a manner consistent with exposure conditions. Although, it is beyond the scope of this document to explain in detail how assessors should address this issue, a discussion (see Appendix A of this chapter) has been included which describes how dose-response factors can be modified to be consistent with the exposure factors for a population of interest. This should serve as a guide for when this issue is a concern.

1.3.3. Approach Used to Develop Recommendations for Exposure Factors

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

> ***Recommendations and Confidence Ratings***
>
> - Recommendations based on data from single or multiple key studies
> - Variability and limitation of the data evaluated
> - Recommendations rated as low, medium, and high confidence

1. Key studies were evaluated in terms of both quality and relevance to specific populations (general U. S. population, age groups, gender, etc.). The criteria for assessing the quality of studies is described in Section 1.3.1.

2. 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 there were multiple key studies, all 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 were chosen as the recommended mean value. If the key studies were judged to be unequal in quality, relevance, or study design, the range of means were presented and the user of this handbook must employ judgment in selecting the most appropriate value for the population of interest. In cases where the national population was of interest, the mid-point of the

range was usually judged to be the most appropriate value.

3. The variability of the factor across the population was discussed. If adequate data were available, the variability was described as either a series of percentiles or a distribution.

4. Limitations of the data were 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 have been used in the derivation of the recommended value.

5. Finally, EPA assigned a confidence rating of low, medium or high to each recommended value. This rating is not intended to represent an uncertainty analysis, rather it represents EPA's judgment on the quality of the underlying data used to derive the recommendation. This judgment was made using the guidelines shown in Table 1-1. Table 1-1 is an adaptation of the General Considerations discussed earlier in Section 1.3.1. Clearly this is a continuum from low to high and judgment was used to determine these ratings. Recommendations given in this handbook are accompanied by a discussion of the rationale for their rating.

Table 1-2 summarizes EPA's recommendations and confidence ratings for the various exposure factors.

It is important to note that the study elements listed in Table 1-1 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 depend on the exposure factor of interest. Also, the relative weights given to the elements for the various factors were subjective and based on the professional judgement of the authors of this handbook. In general, most studies would rank high with regard to "level of peer review," "accessibility," "focus on the factor of interest," and "data pertinent to the U.S." These elements are important for the study to be included in this handbook. However, a high score of these elements does not necessarily translate into a high overall score. Other elements in Table 1-1 were also examined to determine the overall score. For example, the adequacy of data collection period may be more important when determining usual intake of foods in a population. On the other hand, it is not as important for factors where long-term variability may be small such as tapwater intake. In the case of tapwater intake, the currency of the data was a critical element in determining the final rating. In addition, some exposure factors are more easily measured than others. For example, soil ingestion by children is estimated by measuring, in the feces, the levels of certain elements found in soil. Body weight, however, can be measured directly and it is, therefore, a more reliable measurement. This is reflected in the 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.

1.3.4. Characterizing Variability

This document attempts to characterize variability of each of the factors. Variability is characterized in one or more of three ways: (1) as tables 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 in this document wherever they were found in the literature. Recommendations on the use of these distributions are made where appropriate based on the adequacy of the supporting data. The list of exposure factors and the way that variability has been characterized (i.e., average, upper percentiles, multiple percentiles, fitted distribution) are presented in Table 1-3. 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 percentile) of the distribution of values for a particular exposure factor.

An attempt was made to present percentile values in the recommendations that are consistent with the exposure estimators defined in the Exposure Guidelines (i.e., mean, 50th, 90th, 95th, 98th, and 99.9th percentile). This was not, however, always possible because either 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 Exposure Guidelines within the context of risk descriptors and not individual exopusure factors. For example, the Guidelines stated

Table 1-1. Considerations Used to Rate Confidence in Recommended Values

CONSIDERATIONS	HIGH CONFIDENCE	LOW CONFIDENCE
Study Elements		
Level of peer review	The studies received high level of peer review (e.g., they appear in peer review journals).	The studies received limited peer review.
Accessibility	The studies are widely available to the public.	The studies are difficult to obtain (e.g., draft reports, unpublished data).
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.
Focus on factor of interest	The studies focused on the exposure factor of interest.	The purpose of the studies was to characterize a related factor.
Data pertinent to U.S.	The studies focused on the U.S. population.	The studies focused on populations outside the U.S.
Primary data	The studies analyzed primary data.	The studies are based on secondary sources.
Currency	The data were published after 1990.	The data were published before 1980.
Adequacy of data collection period	The study design captures the measurement of interest (e.g., usual consumption patterns of a population).	The study design does not very accurately capture the measurement of interest.
Validity of approach	The studies used the best methodology available to capture the measurement of interest.	There are serious limitations with the approach used.
Study sizes	The sample size is greater than 100 samples.	The sample size is less than 20 samples.
	The sample size depends on how the target population is defined. As the size of a sample relative to the total size of the target population increases, estimates are made with greater statistical assurance that the sample results reflect actual characteristics of the target population.	
Representativeness of the population	The study population is the same as population of interest.	The study population is very different from the population of interest.[a]
Variability in the population	The studies characterized variability in the population studied.	The characterization of variability is limited.
Lack of bias in study design (a high rating is desirable)	Potential bias in the studies are stated or can be determined from the study design.	The study design introduces biases in the results.
Response rates		
In-person interviews	The response rate is greater than 80 percent.	The response rate is less than 40 percent.
Telephone interviews	The response rate is greater than 80 percent.	The response rate is less than 40 percent.
Mail surveys	The response rate is greater than 70 percent.	The response rate is less than 40 percent.
Measurement error	The study design minimizes measurement errors.	Uncertainties with the data exist due to measurement error.
Other Elements		
Number of studies	The number of studies is greater than 3.	The number of studies is 1.
Agreement between researchers	The results of studies from different researchers are in agreement.	The results of studies from different researchers are in disagreement.

[a] Differences include age, sex, race, income, or other demographic parameters.

Table 1-2. Summary of Exposure Factor Recommendations and Confidence Ratings

EXPOSURE FACTOR	RECOMMENDATION	CONFIDENCE RATING
Drinking water intake rate	21 ml/kg-day/1.4 L/day (average)	Medium
	34 ml/kg-day/2.3 L/day (90th percentile)	Medium
	Percentiles and distribution also included	
	Means and percentiles also included for pregnant and lactating women	
Total fruit intake rate	3.4 g/kg-day (per capita average)	Medium
	12.4 g/kg-day (per capita 95th percentile)	Low
	Percentiles also included	
	Means presented for individual fruits	
Total vegetable intake rate	4.3 g/kg-day (per capita average)	Medium
	10 g/kg-day (per capita 95th percentile)	Low
	Percentiles also included	
	Means presented for individual vegetables	
Total meat intake rate	2.1 g/kg-day (per capita average)	Medium
	5.1 g/kg-day (per capita 95th percentile)	Low
	Percentiles also included	
	Percentiles also presented for individual meats	
Total dairy intake rate	8.0 g/kg-day (per capita average)	Medium
	29.7 g/kg-day (per capita 95th percentile)	Low
	Percentiles also included	
	Means presented for individual dairy products	
Grain intake	4.1 g/kg-day (per capita average)	High
	10.8 g/kg-day (per capita 95th percentile)	Low in long-term upper percentiles
	Percentiles also included	
Breast milk intake rate	742 ml/day (average)	Medium
	1,033 ml/day (upper percentile)	Medium
Fish intake rate	General Population	
	20.1 g/day (total fish) average	High
	14.1 g/day (marine) average	High
	6.0 g/day (freshwater/estuarine)average	High
	63 g/day (total fish) 95th percentile long-term	Medium
	Percentiles also included	
	Serving size	High
	129 g (average)	High
	326 g (95th percentile)	
	Recreational marine anglers	Medium
	2 - 7 g/day (finfish only)	
	Recreational freshwater	Medium
	8 g/day (average)	Medium
	25 g/day (95th percentile)	
	Native American Subsistence Population	Medium
	70 g/day (average)	Low
	170 g/day (95th percentile)	

Table 1-2. Summary of Exposure Factor Recommendations and Confidence Ratings (continued)

EXPOSURE FACTOR	RECOMMENDATION	CONFIDENCE RATING
Home produced food intake	Total Fruits 2.7 g/kg-day (consumer only average) 11.1 g/kg-day (consumer only 95th percentile) Percentiles also included Total vegetables 2.1 g/kg-day (consumer only average) 7.5 g/kg-day (consumer only 95th percentile) Percentiles also included Total meats 2.2 g/kg-day (consumer only average) 6.8 g/kg-day (consumer only 95th percentile) Percentiles also included Total dairy products 14 g/kg-day (consumer only average) 44 g/kg-day (consumer only 95th percentile) Percentiles also included	Medium (for means and short-term distributions) Low (for long-term distributions)
Inhalation rate	Children (< 1 year) 4.5 m^3/day (average)	High
	Children (1-12 years) 8.7 m^3/day (average)	High
	Adult Females 11.3 m^3/day (average)	High
	Adult Males 15.2 m^3/day (average)	High
Surface area	Water contact (bathing and swimming) Use total body surface area for children in Tables 6-6 through 6-8; for adults use Tables 6-2 through 6-4 (percentiles are included)	High
	Soil contact (outdoor activities) Use whole body part area based on Table 6-6 through 6-8 for children and 6-2 through 6-4 for adults (percentiles are included)	High
Soil adherence	Use values presented in Table 6-16 depending on activity and body part (central estimates only)	Low
Soil ingestion rate	Children 100 mg/day (average) 400 mg/day (upper percentile)	Medium
	Adults 50 mg/day (average)	Low
	Pica child 10 g/day	Low
Life expectancy	75 years	High
Body weight for adults	71.8 kg Percentiles also presented in tables 7-4 and 7-5	High
Body weights for children	Use values presented in Tables 7-6 and 7-7 (mean and percentiles)	High
Body weights for infants (birth to 6 months)	Use values presented in Table 7-1 (percentiles)	High

Table 1-2. Summary of Exposure Factor Recommendations and Confidence Ratings (continued)

EXPOSURE FACTOR	RECOMMENDATION	CONFIDENCE RATING
Showering/Bathing	Showering time	High
	10 min/day (average)	
	35 min/day (95th percentile)	
	(percentiles are also included)	
	Bathing time	High
	20 min/event (median)	
	45 min/event (90th percentile)	
	Bathing/showering frequency	High
	1 shower event/day	
Swimming	Frequency	High
	1 event/month	
	Duration	High
	60 min/event (median)	
	180 min/event (90th percentile)	
Time indoors	Children (ages 3-11)	Medium
	19 hr/day (weekdays)	
	17 hr/day (weekends)	
	Adults (ages 12 and older)	Medium
	21 hr/day	
	Residential	High
	16.4 hrs/day	
Time outdoors	Children (ages 3-11)	Medium
	5 hr/day (weekdays)	
	7 hr/day (weekends)	
	Adults	Medium
	1.5 hr/day	
	Residential	High
	2 hrs/day	
Time spent inside vehicle	Adults	
	1 hr 20 min/day	Medium
Occupational tenure	6.6 years (16 years old and older)	High
Population mobility	9 years (average)	Medium
	30 years (95th percentile)	Medium
Residence volume	369 m^3 (average)	Medium
	217 m^3 (conservative)	Medium
Residential air exchange	0.45 (median)	Low
	0.18 (conservative)	Low

Table 1-3. Characterization of Variability in Exposure Factors

Exposure Factors	Average	Upper percentile	Multiple Percentiles	Fitted Distributions
Drinking water intake rate	✓	✓	✓	✓
Total fruits and total vegetables intake rate	✓	✓ Qualitative discussion for long-term	✓	
Individual fruits and individual vegetables intake rate	✓			
Total meats and dairy products intake rate	✓	✓ Qualitative discussion for long-term	✓	
Individual meats and dairy products intake rate	✓			
Grains intake	✓	✓	✓	
Breast milk intake rate	✓	✓		
Fish intake rate for general population, recreational marine, recreational freshwater, and native american	✓	✓		
Serving size for fish	✓	✓	✓	
Homeproduced food intake rates	✓	✓	✓	
Soil intake rate	✓	Qualitative discussion for long-term		
Inhalation rate	✓	✓		
Surface area	✓	✓	✓	
Soil adherence	✓			
Life expectancy	✓			
Body weight	✓	✓	✓	
Time indoors	✓			
Time outdoors	✓			
Showering time	✓	✓	✓	
Occupational tenure	✓			
Population mobility	✓	✓	✓	
Residence volume	✓			
Residential air exchange	✓			

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 use of Monte Carlo or other probabilistic analysis require a selection of distributions or histograms for the input parameters. Although this handbook is not intended to provide a complete guidance on the use of Monte Carlo and other probabilistic analyses, the following should be considered 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. Probabilistic analysis is also not necessary when conducting assessments for screening

purposes, i.e., to determine if unimportant pathways can be eliminated. In this case, bounding estimates can be calculated using maximum or near maximum values for each of the input parameters.

- It is important to note that the selection of distributions can be highly site specific and will always involve some degree of judgment. Distributions derived from national data may not represent local conditions. To the extent possible, an assessor should use distributions or frequency histograms derived from local surveys to assess risks locally. When distributional data are drawn from national or other surrogate population, it is important that the assessor address the extent to which local conditions may differ from the surrogate data.

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

- Distribution functions to be used in Monte Carlo 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 way is to avoid the problem by using the empirical data itself rather than an analytic function. Another is to do separate analyses with several functions which 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 such as Statistical Methods for Environmental Pollution Monitoring, Gilbert, R.O., 1987, Van Nostrand Reinhold; off-the-shelf computer software such as Best-Fit by Palisade Corporation can be used to statistically determine the distributions that fit the data.

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

  - keep that variable constant at its central value;
  - assume several values within the range of values for the exposure factor;
  - calculate a point estimate(s) instead of using probabilistic analysis; and
  - assume a distribution (The rationale for the selection of a distribution should be discussed at length.) There are, however, cases where assuming a distribution is not recommended. These include:
    - data are missing or very limited for a key parameter - examples include: soil ingestion by adults;
    - data were collected over a short time period and may not represent long term trends (the respondent 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 - examples include: 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 - examples include: soil ingestion by children.

1.4. GENERAL EQUATION FOR CALCULATING DOSE

The definition of exposure as used in the Exposure Guidelines (U.S. EPA, 1992a) is "condition of a

chemical contacting the outer boundary of a human." This means contact with the visible exterior of a person such as the skin, and openings such as the mouth, nostrils, and lesions. The process of a chemical entering the body can be described in two steps: contact (exposure), followed by entry (crossing the boundary). The magnitude of exposure (dose) is the amount of agent available at human exchange boundaries (skin, lungs, gut) where absorption takes place during some specified time. An example of exposure and dose for the oral route as presented in the the EPA Exposure Guidelines is shown in Figure 1-1. Starting with a general integral equation for exposure (U.S. EPA 1992a), several dose equations can be derived depending upon boundary assumptions. One of the more useful of these derived equations is the Average Daily Dose (ADD). The ADD, which is used for many noncancer effects, averages exposures or doses over the period of time over which exposure occurred. The ADD can be calculated by averaging the potential dose (D_{pot}) over body weight and an averaging time.

$$ADD_{pot} = \frac{\text{Total Potential Dose}}{\text{Body Weight} \times \text{Averaging Time}} \qquad \text{(Eqn. 1-1)}$$

For cancer effects, where the biological response is usually described in terms of lifetime probabilities, even though exposure does not occur over the entire lifetime, doses are often presented as lifetime average daily doses (LADDs). The LADD takes the form of the Equation 1-1 with lifetime replacing averaging time. The LADD is a very common term used in carcinogen risk assessment where linear non-threshold models are employed.

The total exposure can be expressed as follows:

$$\text{Total Potential Dose} = C \times IR \times ED \qquad \text{(Eqn. 1-2)}$$

Where:

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

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

The intake rate refers to the rates of inhalation, ingestion, and dermal contact depending on the route of exposure. For ingestion, the intake rate is simply the amount of food containing the contaminant of interest that an individual ingests during some specific time period (units of mass/time). Much of this handbook is devoted to rates of ingestion for some broad classes of food. For inhalation, the intake rate is the rate at which contaminated air is inhaled. Factors that affect dermal exposure are the amount of material that comes into contact with the skin, and the rate at which the contaminant is absorbed.

The exposure duration is the length of time that contaminant contact lasts. The time a person lives in an area, frequency of bathing, time spent indoors versus outdoors, etc. all affect the exposure duration. The Activity Factors Chapter (Volume III, Chapter 15) gives some examples of population behavior patterns, which may be useful for estimating exposure durations to be used in the exposure calculations.

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

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

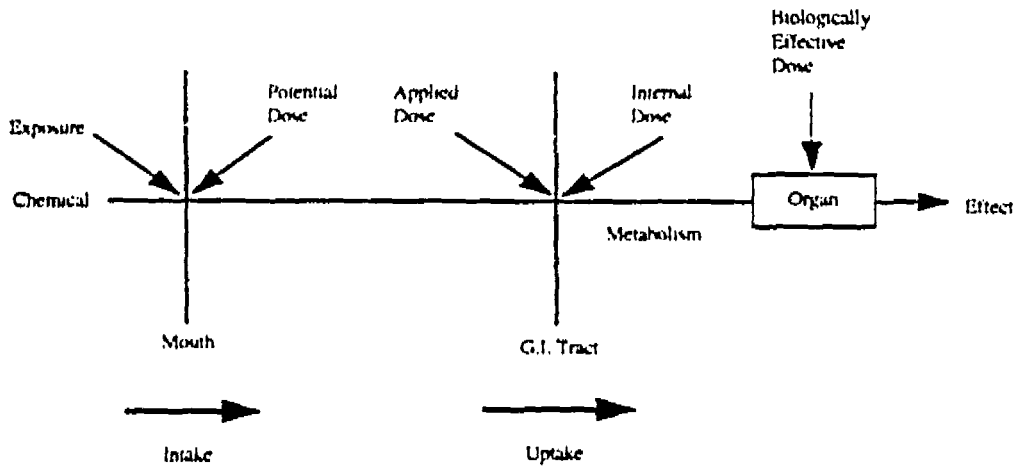


Figure 1-1. Schematic of Dose and Exposure: Oral Route

Source: U.S. EPA, 1992a

used in the derivation of the dose-response factor is inappropriate.

The lifetime value used in the LADD version of Equation 1-1 is the period of time over which the dose is averaged. For carcinogens, the derivation of the dose-response parameters usually assumes no explicit number of years as the duration of a lifetime, and the nominal value of 75 years is considered a reasonable approximation. For exposure estimates to be used for assessments other than carcinogenic risk, various averaging periods have been used. For acute exposures, the administered doses are usually averaged over a day or a single event. For nonchronic noncancer effects, the time period used is the actual period of exposure. The objective in selecting the exposure averaging time is to express the exposure in a way which can be combined with the dose-response relationship to calculate risk.

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

The units of intake in this handbook for the ingestion of fish, breast milk, and the inhalation of air are not normalized to body weight. In this case, the exposure assessor needs to use (in Equation 1-1) the average weight of the exposed population during the time when the exposure actually occurs. If the exposure occurs continuously throughout an individual's life or only during the adult ages, using an adult weight of 71.8 kg should provide sufficient accuracy. If the body weight of the individuals in the population whose risk is being evaluated is non-standard in some way, such as for children or for first-generation immigrants who may be smaller than the national population, and if reasonable values are not available in the literature, then a model of intake as a function of body weight must be used. One such model is discussed in Appendix 1A of this chapter. Some of the parameters (primarily concentrations) used in estimating exposure are exclusively site specific, and therefore default recommendations could not be used.

The food ingestion rate values provided in this handbook are generally expressed as "as consumed" since this is the fashion in which data are reported by

survey respondents. This is of importance because concentration data to be used in the dose equation are generally measured in uncooked food samples. In most situations, the only practical choice is to use the "as consumed" ingestion rate and the uncooked concentration. However, it should be recognized that cooking generally results in some reductions in weight (e.g., loss of moisture), and that if the mass of the contaminant in the food remains constant, then the concentration of the contaminant in the cooked food item will increase. Therefore, if the "as consumed" ingestion rate and the uncooked concentration are used in the dose equation, dose may be underestimated. On the other hand, cooking may cause a reduction in mass of contaminant and other ingredients such that the overall concentration of contaminant does not change significantly. In this case, combining cooked ingestion rates and uncooked concentration will provide an appropriate estimate of dose. Ideally, food concentration data should be adjusted to account for changes after cooking, then the "as consumed" intake rates are appropriate. In the absence of data, it is reasonable to assume that no change in contaminant concentration occurs after cooking. Except for general population fish consumption and home produced foods, uncooked intake rate data were not available for presention in this handbook. Data on the general population fish consumption have been presented in this handbook (Section 10.2) in both "as consumed" and uncooked basis. It is important for the assessor to be aware of these issues and choose intake rate data that best matches the concentration data that is being used.

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, such as 129 g of fish eaten per meal (U.S. EPA, 1996). The duration should be based on the number of events or, in this case, meals.

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

The objective is to define the terms so that when multiplied, they give the appropriate estimate of mass of contaminant contacted. This can be accomplished by basing the intake rate on either a long-term average (chronic exposure) or an event (acute exposure) basis, as long as the duration value is selected appropriately. Consider the case in which a person eats a 129-g fish meal approximately five times per month (long-term average is 21.5 g/day) for 30 years; or 21.5 g/day of fish every day for 30 years.

$$(129\ g/meal)(5\ meals/mo)(mo/30\ d)(365\ d/yr)(30\ yrs) = 235{,}425\ g$$

$$(21.5\ g/day)(365\ d/yr)(30\ yrs) = 235{,}425\ g$$

Thus, a frequency of either 60 meals/year or a duration of 365 days/year could be used as long as it is matched with the appropriate intake rate.

1.5. RESEARCH NEEDS

In an earlier draft of this handbook, reviewers were asked to identify factors or areas where further research is needed The following list is a compilation of areas for future research identified by the peer reviewers and authors of this document:

- The data and information available with respect to occupational exposures are quite limited. Efforts need to be directed to identify data or references on occupational exposure.

- Further research is necessary to refine estimates of fish consumption, particularly by subpopulations of subsistence fishermen.

- Research is needed to better estimate soil intake rates, particularly how to extrapolate short-term data to chronic exposures. Data on soil intake rates by adults are very limited. Research in this area is also recommended. Research is also needed to refine methods to calculate soil intake rate (i.e., inconsistencies among tracers and input/output misalignment errors indicate a fundamental problem with the methods). Research is also needed to obtain more data to better estimate soil adherence.

- In cases where several studies of equal quality and data collection procedures are available for an exposure factor, procedures need to be developed to combine the data in order to create a single distribution of likely values for that factor.

- Reviewers recommended that the handbook be made available in CD ROM and that the data presented be made available in a format that will allow the users to conduct their own analysis. The intent is to provide a comprehensive factors tool with interactive menu to guide users to areas of interest, word searching features, and data base files.

- Reviewers recommended that EPA derive distribution functions using the empirical data for the various exposure factors to be used in Monte Carlo or other probabilistic analysis.

- Research is needed to derive a methodology to extrapolate from short-term data to long-term or chronic exposures.

- Reviewers recommended that the consumer products chapter be expanded to include more products. A comprehensive literature search needs to be conducted to investigate other sources of data.

- Breastmilk intake.

- More recent data on tapwater intake.

- SAB recommended analysis of 1994 and 1995 CSFII data.

1.6. ORGANIZATION

The handbook is organized into three volumes as follows:

Volume I - General Factors

Chapter 1 Provides the overall introduction to the handbook

Chapter 2 Presents an analysis of uncertainty and discusses methods that can be used to evaluate and present the uncertainty associated with exposure scenario estimates.

Chapter 3 Provides factors for estimating human exposure through ingestion of water.

Chapter 4 Provides factors for estimating exposure through ingestion of soil.

Chapter 5 Provides factors for estimating exposure as a result of inhalation of vapors and particulates.

Chapter 6 Presents factors for estimating dermal exposure to environmental contaminants that come in contact with the skin.

Chapter 7 Provides data on body weight.

Chapter 8 Provides data on life expectancy.

Volume II - Ingestion Factors

Chapter 9 Provides factors for estimating exposure through ingestion of fruits and vegetables.

Chapter 10 Provides factors for estimating exposure through ingestion of fish.

Chapter 11 Provides factors for estimating exposure through ingestion of meats and dairy products.

Chapter 12 Presents data for estimating exposure through ingestion of grain products.

Chapter 13 Presents factors for estimating exposure through ingestion of home produced food.

Chapter 14 Presents data for estimating exposure through ingestion of breast milk.

Volume III - Activity Factors

Chapter 15 Presents data on activity factors (activity patterns, population mobility, and occupational mobility).

Chapter 16 Presents data on consumer product use.

Chapter 17 Presents factors used in estimating residential exposures.

Figure 1-2 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. A glossary is provided at the end of Volume III.

1.7. REFERENCES FOR CHAPTER 1

AIHC. (1994) Exposure factors sourcebook. Washington, DC: American Industrial Health Council.

Calabrese, E.J.; Pastides, H.; Barnes, R.; Edwards, C.; Kostecki, P.T.; et al. (1989) How much soil do young children ingest: an epidemiologic study. In: Petroleum Contaminated Soils, Lewis Publishers, Chelsea, MI. pp. 363-397.

Gilbert, R.O. (1987) Statistical methods for environmental pollution monitoring. New York: Van Nostrand Reinhold.

U.S. EPA. (1983-1989) Methods for assessing exposure to chemical substances. Volumes 1-13. Washington, DC: Office of Toxic Substances, Exposure Evaluation Division.

U.S. EPA. (1984) Pesticide assessment guidelines subdivision K, exposure: reentry protection. Office of Pesticide Programs, Washington, DC. EPA/540/9-48/001. Available from NTIS, Springfield, VA; PB-85-120962.

U.S. EPA. (1986a) Standard scenarios for estimating exposure to chemical substances during use of consumer products. Volumes I and II. Washington, DC: Office of Toxic Substance, Exposure Evaluation Division.

U.S. EPA. (1986b) Pesticide assessment guidelines subdivision U, applicator exposure monitoring. Office of Pesticide Programs, Washington, DC. EPA/540/9-87/127. Available from NTIS, Springfield, VA; PB-85-133286.

U.S. EPA. (1987) Selection criteria for mathematical models used in exposure assessments: surface water models. Exposure Assessment Group, Office of Health and Environmental Assessment, Washington, DC. WPA/600/8-87/042. Available from NTIS, Springfield, VA; PB-88-139928/AS.

U.S. EPA. (1988a) Superfund exposure assessment manual. Office of Emergency and Remedial Response, Washington, DC. EPA/540/1-88/001. Available from NTIS, Springfield, VA; PB-89-135859.

U.S. EPA. (1988b) Selection criteria for mathematical models used in exposure assessments: groundwater models. Exposure Assessment Group, Office of Health and Environmental Assessment, Washington, DC. EPA/600/8-88/075. Available from NTIS, Springfield, VA; PB-88-248752/AS.

U.S. EPA. (1989) Risk assessment guidance for Superfund. Human health evaluation manual: part A. Interim Final. Office of Solid Waste and Emergency Response, Washington, DC. Available from NTIS, Springfield, VA; PB-90-155581.

U.S. EPA. (1990) Methodology for assessing health risks associated with indirect exposure to combustor emissions. EPA 600/6-90/003. Available from NTIS, Springfield, VA; PB-90-187055/AS.

U.S. EPA. (1992a) Guidelines for exposure assessment. Washington, DC: Office of Research and Development, Office of Health and Environmental Assessment. EPA/600/Z-92/001.

U.S. EPA. (1992b) Dermal exposure assessment: principles and applications. Washington, DC: Office of Health and Environmental Assessments. EPA/600/8-9/011F.

U.S. EPA. (1994) Estimating exposures to dioxin-like compounds. (Draft Report). Office of Research and Development, Washington, DC. EPA/600/6-88/005Cb.

U.S. EPA. (1996) Daily average per capita fish consumption estimates based on the combined 1989, 1990, and 1999 continuing survey of food intakes by individuals (CSFII) 1989-91 data. Volumes I and II. Preliminary Draft Report. Washington, DC: Office of Water.

Figure 1-2. Road Map to Exposure Factor Recommendations

EXPOSURE ROUTE	EXPOSURE FACTOR	POPULATION	VOLUME	CHAPTER	RECOMMENDATIONS/ RATINGS TABLE PAGE NOS.
Ingestion	Drinking Water Intake Rate	Adults	I	3.	3-23/3-39
		Children			
		Pregnant Women			
		High Activity			
	Fruit and Vegetable Intake Rate	Various Demographic Groups — Age, Region, Season, Urbanization, Race	II	9.	9-7/9-45
	Meat and Dairy Intake Rate		II	11.	11-7/11-32
	Homegrown Foods		II	13.	13-10/13-67
	Breast milk Intake Rate	Nursing Infants	II	14.	14-7/14-13
	Fish and Shellfish Intake Rate	General Population	II	10.	10-25/10-85
		Freshwater Recreational	II	10.	10-26/10-87
		Marine Recreational	II	10.	10-26/10-86
		Subsistence	II	10.	10-26/10-88
	Soil Intake Rate	Typical Children	I	4.	4-20/4-21
		Adults			
		Pica Children			
	Grain Intake	Various Demographic Groups — Age, Region, Season, Urbanization, Race	II	12.	12-5/12-23
Inhalation	Inhalation Rate	Adults	I	5.	5-22/5-23
		Children			
		High Activity			
Dermal	Skin Surface Area	Adults	I	6.	6-8/6-25
		Children			
	Soil Adherence	General Population	I	6.	6-8/6-27
(All Routes) Human Characteristics	Body Weight	Adults	I	7.	7-10/7-12
		Children			
	Lifetime	Adults	I	8.	8-1/8-5
		Children			
(All Routes) Activity Factors	Activity Patterns	Adults	III	15.	15-15/15-164
		Children			
	Occupational Mobility	Adults	III	15.	15-17/15-171
	Population Mobility	Adults	III	15.	15-17/15-172
		Children			
(All Routes) Consumer Product Use	Frequency of Use	Adults	III	16.	16-5
	Amount Used	Adults			
(All Routes) Residential Building Characteristics	Water Use	General Population	III	17.	17-6/17-30, 17-31
	Air Exchange Rates				
	House Volumes				
	Building Characteristics				

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 IRIS

1. INTRODUCTION

When calculating risk estimates for a specific population, whether the entire national population or some sub-population, the exposure information (either from this handbook or from other data) must be combined with dose-response information. The latter typically comes from the IRIS data base, which summarizes toxicity data for each agent separately. Care must be taken that the assumptions about population parameters in the dose-response analysis are consistent with the population parameters used in the exposure analysis. This Appendix discusses procedures for insuring this consistency.

In the IRIS derivation of threshold based dose-response relationships (U.S. EPA, 1996), such as the RfD and the RfCs based on adverse systemic effects, there has generally been no explicit use of human exposure factors. In these cases the numerical value of the RfD and RfC comes directly from animal dosing experiments (and occasionally from human studies) and from the application of uncertainty factors to reflect issues such as the duration of the experiment, the fact that animals are being used to represent humans and the quality of the study. However in developing cancer dose-response (D-R) assessments, a standard exposure scenario is assumed in calculating the slope factor (i.e., human cancer risk per unit dose) on the basis of either animal bioassay data or human data. This standard scenario has traditionally been assumed to be typical of the U.S. population: 1) body weight = 70 kg; 2) air intake rate = 20 m^3/day; 3) drinking water intake = 2 liters/day; 4) lifetime = 70 years. In RfC derivations for cases involving an adverse effect on the respiratory tract, the air intake rate of 20 m^3/day is assumed. The use of these specific values has depended on whether the slope factor was derived from animal or human epidemiologic data:

- Animal Data: For dose-resopnse (D-R) studies based on animal data, scale animal doses to human equivalent doses using a human body weight assumption of 70 kg. No explicit lifetime adjustment is necessary because the assumption is made that events occurring in the lifetime animal bioassay will occur with equal probability in a human lifetime, whatever that might happen to be.

- Human Data - In the analysis of human studies (either occupational or general population), the Agency has usually made no explicit assumption of body weight or human lifetime. For both of these parameters there is an implicit assumption that the population usually of interest has the same descriptive parameters as the population analyzed by the Agency. In the rare situation where this assumption is known to be wrong, the Agency has made appropriate corrections so that the dose-response parameters represent the national average population.

When the population of interest is different than the national average (standard) population, the dose-response parameter needs to be adjusted. In addition, when the population of interest is different than the population from which the exposure factors in this handbook were derived, the exposure factor needs to be adjusted. Two generic examples of situations where these adjustments are needed are as follows:

A) Detailed study of recent data, such as are presented in this handbook, show that EPA's standard assumptions (i.e., 70 kg body weight, 20 m^3/day air inhaled, and 2 L/day water intake) are inaccurate for the national population and may be inappropriate for sub-populations under consideration. The handbook addresses most of these situations by providing gender- and age-specific values and by normalizing the intake values to body weight when the data are available, but it may not have covered all possible situations. An example of a sub-population with a different mean

body weight would be females, with an average body weight of 60 kg or children with a body weight dependent on age. Another example of a non-standard sub-population would be a sedentary hospital population with lower than 20 m^3/day air intake rates.

B) The population variability of these parameters is of interest and it is desired to estimate percentile limits of the population variation. Although the detailed methods for estimating percentile limits of exposure and risk in a population are beyond the scope of this document, one would treat the body weight and the intake rates discussed in Sections 2 to 4 of this appendix as distributions, rather than constants.

2. CORRECTIONS FOR DOSE-RESPONSE PARAMETERS

The correction factors for the dose-response values tabulated in the IRIS data base for carcinogens are summarized in Table 1A-1. Use of these correction parameters is necessary to avoid introducing errors into the risk analysis. The second column of Table 1A-1 shows the dependencies that have been assumed in the typical situation where the human dose-response factors have been derived from the administered dose in animal studies. 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 pharmacokinetic model and b) the dose-response data has been derived from human data. In the former case, the subpopulation 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 in the derivation of the parameter.

Table 1A-1. Procedures for Modifying IRIS Risk Values for Non-standard Populations[a,b]

IRIS Risk Measure [Units]	IRIS Risk Measure is Proportional to:[b]	Correction Factor (CF) for modifying IRIS Risk Measures:[c]
Slope Factor [per mg/(kg/day)]	$(W^S)^{1/3} = (70)^{1/3}$	$(W^P/70)^{1/3}$
Water Unit Risk [per μg/l]	$I_W^S/[(W^S)^{2/3}] = 2/[(70)^{2/3}]$	$(I_W^P)/2 \times [70/(W^P)]^{2/3}$
Air Unit Risk: A. Particles or aerosols [per $\mu g/m^3$], air concentration by weight	$I_A^S/[(W^S)^{2/3}] = 20/[(70)^{2/3}]$	$(I_A^P)/20 \times [70/(W^P)]^{2/3}$
Air Unit Risk: B. Gases [per parts per million], air concentration by volume.	No explicit proportionality to body weight or air intake is assumed.	1.0 ppm by volume is assumed to be the effective dose in both animals and humans.

[a] W = Body weight (kg)
I_W = Drinking water intake (liters per day)
I_A = Air intake (cubic meters per day)

[b] W^S, I_W^S, I_A^S denote standard parameters assumed by IRIS

[c] Modified risk measure = (CF) x IRIS value
W^P, I_W^P, I_A^P denote non-standard parameters of the actual population

As one example of the use of Table 1A-1, the recommended value for the average consumption of tapwater for adults in the U. S. population derived in this document (Chapter 3), is 1.4 liters per day. The drinking water unit risk for dichlorvos, as given in the IRIS information data base is 8.3×10^{-6} per $\mu g/l$, and was calculated from the slope factor assuming the standard intake, I_W^S, of 2 liters per day. For the United States population drinking 1.4 liters of tap water per day the corrected drinking water unit risk should be $8.3 \times 10^{-6} \times (1.4/2) = 5.8 \times 10^{-6}$ per $\mu g/l$. The risk to the average individual is then estimated by multiplying this by the average concentration in units of $\mu g/l$.

Another example is when the risk for women drinking water contaminated with dichlorvos is to be estimated. If the women have an average body weight of 60 kg, the correction factor for the drinking water unit risk is (disregarding the correction discussed in the above paragraph), from Table 1A-1, is $(70/60)^{2/3} = 1.11$. Here the ratio of 70 to 60 is raised to the power of 2/3. The corrected water unit risk for dichlorvos is $8.3 \times 10^{-6} \times 1.11 = 9.2 \times 10^{-6}$ per $\mu g/l$. As before, the risk to the average individual is estimated by multiplying this by the water concentration.

When human data are used to derive the risk measure, there is a large variation in the different data sets encountered in IRIS, so no generalizations can be made about global corrections. However, the typical default exposure values used for the air intake of an air pollutant over an occupational lifetime are: air intake is 10 m^3/day for an 8-hour shift, 240 days per year with 40 years on the job. If there is continuous exposure to an ambient air pollutant, the lifetime dose is usually calculated assuming a 70-year lifetime.

3. CORRECTIONS FOR INTAKE DATA

When the body weight, W^P, of the population of interest differs from the body weight, W^E, of the population from which the exposure values in this handbook were derived, the following model furnishes a reasonable basis for estimating the intake of food and air (and probably water also) in the population of interest. Such a model is needed in the absence of data on the dependency of intake on body size. This occurs for inhalation data, where the intake data are not normalized to body weight, whereas the model is not needed for food and tap water intakes if they are given in units of intake per kg body weight.

The model is based on the dependency of metabolic oxygen consumption on body size. Oxygen consumption is directly related to food (calorie) consumption and air intake and indirectly to water intake. For mammals of a wide range of species sizes (Prosser and Brown, 1961), and also for individuals of various sizes within a species, the oxygen consumption and calorie (food) intake varies as the body weight raised to a power between 0.65 and 0.75. A value of 0.667 = 2/3 has been used in EPA as the default value for adjusting cross-species intakes, and the same factor has been used for intra-species intake adjustments.

[NOTE: Following discussions by an interagency task force (Federal Register, 1992), the agreement was that a more accurate and defensible default value would be to choose the power to 3/4 rather than 2/3. A recent article (West et al., 1997) has provided a theoretical basis for the 3/4 power scaling. This will be the standard value to be used in future assessments, and all equations in this Appendix will be modified in future risk assessments. However, because risk assessors now use the current IRIS information, this discussion is presented with the previous default assumption of 2/3].

With this model, the relation between the daily air intake in the population of interest, $I_A^P = (m^3/day)^P$, and the intake in the population described in this handbook, $I_A^E = (m^3/day)^E$ is:

$$I_A^P = I_A^E \times (W^P/W^E)^{2/3}.$$

4. CALCULATION OF RISKS FOR AIR CONTAMINANTS

The risk is calculated by multiplying the IRIS air unit risk, corrected as described in Table 1A-1, by the air concentration. But since the correction factor involves the intake in the population of interest (I_A^P), that quantity must be included in the equation, as follows:

$$
\begin{aligned}
(\text{Risk})^P &= (\text{air unit risk})^P \times (\text{air concentration}) \\
&= (\text{air unit risk})^S \times (I_A^P/20) \times (70/W^P)^{2/3} \times (\text{air concentration}) \\
&= (\text{air unit risk})^S \times [(I_A^E \times (W^P/W^E)^{2/3}/20)] \times (70/W^P)^{2/3} \times (\text{air concentration}) \\
&= (\text{air unit risk})^S \times (I_A^E/20) \times (70/W^E)^{2/3} \times (\text{air concentration})
\end{aligned}
$$

In this equation the air unit risk from the IRIS data base (air unit risk)^S, the air intake data in the handbook for the populations where it is available (I_A^E) and the body weight of that population (W^E) are included along with the standard IRIS values of the air intake (20 m^3/day) and body weight (70 kg).

For food ingestion and tap water intake, if body weight-normalized intake values from this handbook are used, the intake data do not have to be corrected as in Section 3 above. In these cases, corrections to the dose-response parameters in Table 1A-1 are sufficient.

5. REFERENCES

Federal Register. (1992) Cross-species scaling factor for carcinogen risk assessments based on equivalence of (mg/kg-day)$^{3/4}$. Draft report. Federal Register, 57(109): 24152-24173, June 5, 1992.

Prosser, C.L.; Brown, F.A. (1961) Comparative Animal physiology, 2nd edition. WB Saunders Co. p. 161.

U.S. EPA. (1996) Background Documentation. Integrated Risk Information System (IRIS). Online. National Center for Environmental Assessment, Cincinnati, Ohio. Background Documentation available from: Risk Information Hotline, National Center for Environmental Assessment, U.S. EPA, 26 W. Martin Luther King Dr. Cincinnati, OH 45268. (513) 569-7254

West, G.B.; Brown, J.H.; Enquist, B.J. (1997) A general model of the origin of allometric scaling laws in biology. Science 276:122-126.

2. VARIABILITY AND UNCERTAINTY

The chapters that follow will discuss exposure factors and algorithms for estimating exposure. Exposure factor values can be used to obtain a range of exposure estimates such as average, high-end and bounding estimates. It is instructive here to return to the general equation for potential Average Daily Dose (ADD_{pot}) that was introduced in the opening chapter of this handbook:

$$ADD_{pot} = \frac{\text{Contaminant Concentration} \times \text{Intake Rate} \times \text{Exposure Duration}}{\text{Body Weight} \times \text{Averaging Time}} \qquad \text{(Eqn 2-1)}$$

With the exception of the contaminant concentration, all parameters in the above equation are considered exposure factors and, thus, are treated in fair detail in other chapters of this handbook. Each of the exposure factors involves humans, either in terms of their characteristics (e.g., body weight) or behaviors (e.g., amount of time spent in a specific location, which affects exposure duration). While the topics of variability and uncertainty apply equally to contaminant concentrations and the rest of the exposure factors in equation 2-1, the focus of this chapter is on variability and uncertainty as they relate to exposure factors. Consequently, examples provided in this chapter relate primarily to exposure factors, although contaminant concentrations may be used when they better illustrate the point under discussion.

This chapter also is intended to acquaint the exposure assessor with some of the fundamental concepts and precepts related to variability and uncertainty, together with methods and considerations for evaluating and presenting the uncertainty associated with exposure estimates. Subsequent sections in this chapter are devoted to the following topics:

- Distinction between variability and uncertainty;
- Types of variability;
- Methods of confronting variability;
- Types of uncertainty and reducing uncertainty;
- Analysis of variability and uncertainty; and
- Presenting results of variability/uncertainty analysis.

Fairly extensive treatises on the topic of uncertainty have been provided, for example, by Morgan and Henrion (1990), the National Research Council (NRC, 1994) and, to a lesser extent, the U.S. EPA (1992; 1995). The topic commonly has been treated as it relates to the overall process of conducting risk assessments; because exposure assessment is a component of risk-assessment process, the general concepts apply equally to the exposure-assessment component.

2.1. VARIABILITY VERSUS UNCERTAINTY

While some authors have treated variability as a specific type or component of uncertainty, the U.S. EPA (1995) has advised the risk assessor (and, by analogy, the exposure assessor) to distinguish between variability and uncertainty. Uncertainty represents a lack of knowledge about factors affecting exposure or risk, whereas variability arises from true heterogeneity across people, places or time. In other words, uncertainty can lead to inaccurate or biased estimates, whereas variability can affect the precision of the estimates and the degree to which they can be generalized. Most of the data presented in this handbook concerns variability.

Variability and uncertainty can complement or confound one another. An instructive analogy has been drawn by the National Research Council (NRC, 1994; Chapter 10), based on the objective of estimating the distance between the earth and the moon. Prior to fairly recent technology developments, it was difficult to make accurate measurements of this distance, resulting in measurement uncertainty. Because the moon's orbit is elliptical, the distance is a variable quantity. If only a few measurements were to be taken without knowledge of the elliptical pattern, then either of the following incorrect conclusions might be reached:

- That the measurements were faulty, thereby ascribing to uncertainty what was actually caused by variability; or
- That the moon's orbit was random, thereby not allowing uncertainty to shed light on seemingly unexplainable differences that are in fact variable and predictable.

A more fundamental error in the above situation would be to incorrectly estimate the true distance, by assuming that a few observations were sufficient. This latter pitfall -- treating a highly variable quantity as if it were invariant or only uncertain -- is probably the most relevant to the exposure or risk assessor.

Now consider a situation that relates to exposure, such as estimating the average daily dose by one exposure

route -- ingestion of contaminated drinking water. Suppose that it is possible to measure an individual's daily water consumption (and concentration of the contaminant) exactly, thereby eliminating uncertainty in the measured daily dose. The daily dose still has an inherent day-to-day variability, however, due to changes in the individual's daily water intake or the contaminant concentration in water.

It is impractical to measure the individual's dose every day. For this reason, the exposure assessor may estimate the average daily dose (ADD) based on a finite number of measurements, in an attempt to "average out" the day-to-day variability. The individual has a true (but unknown) ADD, which has now been estimated based on a sample of measurements. Because the individual's true average is unknown, it is uncertain how close the estimate is to the true value. Thus, the variability across daily doses has been translated into uncertainty in the ADD. Although the individual's true ADD has no variability, the estimate of the ADD has some uncertainty.

The above discussion pertains to the ADD for one person. Now consider a distribution of ADDs across individuals in a defined population (e.g., the general U.S. population). In this case, variability refers to the range and distribution of ADDs across individuals in the population. By comparison, uncertainty refers to the exposure assessor's state of knowledge about that distribution, or about parameters describing the distribution (e.g., mean, standard deviation, general shape, various percentiles).

As noted by the National Research Council (NRC, 1994), the realms of variability and uncertainty have fundamentally different ramifications for science and judgment. For example, uncertainty may force decision-makers to judge how probable it is that exposures have been overestimated or underestimated for every member of the exposed population, whereas variability forces them to cope with the certainty that different individuals are subject to exposures both above and below any of the exposure levels chosen as a reference point.

2.2. TYPES OF VARIABILITY

Variability in exposure is related to an individual's location, activity, and behavior or preferences at a particular point in time, as well as pollutant emission rates and physical/chemical processes that affect concentrations in various media (e.g., air, soil, food and water). The variations in pollutant-specific emissions or processes, and in individual locations, activities or behaviors, are not necessarily independent of one another. For example, both personal activities and pollutant concentrations at a specific location might vary in response to weather conditions, or between weekdays and weekends.

At a more fundamental level, three types of variability can be distinguished:

- Variability across locations (Spatial Variability);
- Variability over time (Temporal Variability); and
- Variability among individuals (Inter-individual Variability).

Spatial variability can occur both at regional (macroscale) and local (microscale) levels. For example, fish intake rates can vary depending on the region of the country. Higher consumption may occur among populations located near large bodies of water such as the Great Lakes or coastal areas. As another 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 the pollutant source, whether it be an industrial plant or related to a personal activity such as showering or gardening. In the context of exposure to airborne pollutants, the concept of a "microenvironment" has been introduced (Duan, 1982) to denote a specific locality (e.g., a residential lot or a room in a specific building) where the airborne concentration can be treated as homogeneous (i.e., invariant) at a particular point in time.

Temporal variability refers to variations over time, whether long- or short-term. Seasonal fluctuations in weather, pesticide applications, use of woodburning appliances and fraction of time spent outdoors are examples of longer-term variability. Examples of shorter-term variability are differences in industrial or personal activities on weekdays versus weekends or at different times of the day.

Inter-individual variability can be either of two types: (1) human characteristics such as age or body weight, and (2) human behaviors such as location and activity patterns. Each of these variabilities, in turn, may be related to several underlying phenomena that vary. For example, the natural variability in human weight is due to a combination of genetic, nutritional, and other lifestyle or environmental factors. Variability arising from independent factors that combine multiplicatively

generally will lead to an approximately lognormal distribution across the population, or across spatial/temporal dimensions.

2.3. CONFRONTING VARIABILITY

According to the National Research Council (NRC 1994), variability can be confronted in four basic ways (Table 2-1) when dealing with science-policy questions surrounding issues such as exposure or risk assessment. The first is to **ignore the variability** and hope for the best. This strategy tends to work best when the variability is relatively small. For example, the assumption that all adults weigh 70 kg is likely to be correct within ±25% for most adults.

The second strategy involves **disaggregating the variability** *in some explicit way, in order to better* understand it or reduce it. Mathematical models are appropriate in some cases, as in fitting a sine wave to the annual outdoor concentration cycle for a particular pollutant and location. In other cases, particularly those involving human characteristics or behaviors, it is easier to disaggregate the data by considering all the relevant subgroups or subpopulations. For example, distributions of body weight could be developed separately for adults, adolescents and children, and even for males and females within each of these subgroups. Temporal and spatial analogies for this concept involve measurements on appropriate time scales and choosing appropriate subregions or microenvironments.

The third strategy is to **use the average value** of a quantity that varies. Although this strategy might appear as tantamount to ignoring variability, it needs to be based on a decision that the average value can be estimated reliably in light of the variability (e.g., when the variability is known to be relatively small, as in the case of adult body weight).

The fourth strategy involves **using the maximum or minimum value** for an exposure factor. In this case, the variability is characterized by the range between the extreme values and a measure of central tendency. This is perhaps the most common method of dealing with variability in exposure or risk assessment -- to focus on one time period (e.g., the period of peak exposure), one spatial region (e.g., in close proximity to the pollutant source of concern), or one subpopulation (e.g., exercising asthmatics). As noted by the U.S. EPA (1992), when an exposure assessor develops estimates of high-end individual exposure and dose, care must be taken not to set all factors to values that maximize exposure or dose -- such an approach will almost always lead to an overestimate.

2.4. CONCERN ABOUT UNCERTAINTY

Why should the exposure assessor be concerned with uncertainty? As noted by the U.S. EPA (1992), exposure assessment can involve a broad array of information sources and analysis techniques. Even in situations where actual exposure-related measurements exist, assumptions or inferences will still be required because data are not likely to be available for all aspects of the exposure assessment. Moreover, the data that are available may be of questionable or unknown quality. Thus, exposure assessors have a responsibility to present not just numbers, but also a clear and explicit explanation of the implications and limitations of their analyses.

Table 2-1. Four Strategies for Confronting Variability

Strategy	Example	Comment
Ignore variability	Assume that all adults weigh 70 kg	Works best when variability is small
Disaggregate the variability	Develop distributions of body weight for age/gender groups	Variability will be smaller in each group
Use the average value	Use average body weight for adults	Can the average be estimated reliably given what is known about the variability?
Use a maximum or minimum value	Use a lower-end value from the weight distribution	Conservative approach -- can lead to unrealistically high exposure estimate if taken for all factors

Morgan and Henrion (1990) provide an argument by analogy. When scientists report quantities that they have measured, they are expected to routinely report an estimate of the probable error associated with such measurements. Because uncertainties inherent in policy analysis (of which exposure assessment is a part) tend to be even greater than those in the natural sciences, exposure assessors also should be expected to report or comment on the uncertainties associated with their estimates.

Additional reasons for addressing uncertainty in exposure or risk assessments (U.S. EPA, 1992; Morgan and Henrion, 1990) include the following:

- Uncertain information from different sources of different quality often must be combined for the assessment;
- Decisions need to be made about whether or how to expend resources to acquire additional information,;
- Biases may result in so-called "best estimates" that in actuality are not very accurate; and
- Important factors and potential sources of disagreement in a problem can be identified.

Addressing uncertainty will increase the likelihood that results of an assessment or analysis will be used in an appropriate manner. Problems rarely are solved to everyone's satisfaction, and decisions rarely are reached on the basis of a single piece of evidence. Results of prior analyses can shed light on current assessments, particularly if they are couched in the context of prevailing uncertainty at the time of analysis. Exposure assessment tends to be an iterative process, beginning with a screening-level assessment that may identify the need for more in-depth assessment. One of the primary goals of the more detailed assessment is to reduce uncertainty in estimated exposures. This objective can be achieved more efficiently if guided by presentation and discussion of factors thought to be primarily responsible for uncertainty in prior estimates.

2.5. TYPES OF UNCERTAINTY AND REDUCING UNCERTAINTY

The problem of uncertainty in exposure or risk assessment is relatively large, and can quickly become too complex for facile treatment unless it is divided into smaller and more manageable topics. One method of division (Bogen, 1990) involves classifying sources of uncertainty according to the step in the risk assessment process (hazard identification, dose-response assessment, exposure assessment or risk characterization) at which they can occur. A more abstract and generalized approach preferred by some scientists is to partition all uncertainties among the three categories of bias, randomness and true variability. These ideas are discussed later in some examples.

The U.S. EPA (1992) has classified uncertainty in exposure assessment into three broad categories:

1. Uncertainty regarding missing or incomplete information needed to fully define exposure and dose (Scenario Uncertainty).
2. Uncertainty regarding some parameter (Parameter Uncertainty).
3. Uncertainty regarding gaps in scientific theory required to make predictions on the basis of causal inferences (Model Uncertainty).

Identification of the sources of uncertainty in an exposure assessment is the first step in determining how to reduce that uncertainty. The types of uncertainty listed above can be further defined by examining their principal causes. Sources and examples for each type of uncertainty are summarized in Table 2-2.

Because uncertainty in exposure assessments is fundamentally tied to a lack of knowledge concerning important exposure factors, strategies for reducing uncertainty necessarily involve reduction or elimination of knowledge gaps. Example strategies to reduce uncertainty include (1) collection of new data using a larger sample size, an unbiased sample design, a more direct measurement method or a more appropriate target population, and (2) use of more sophisticated modeling and analysis tools.

2.6. ANALYZING VARIABILITY AND UNCERTAINTY

Exposure assessments often are developed in a phased approach. The initial phase 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 that would fall on or beyond the high end of the expected exposure distribution. Because screening-level analyses usually are included in the final exposure assessment, the final document may contain scenarios that differ quite markedly in

Table 2-2. Three Types of Uncertainty and Associated Sources and Examples

Type of Uncertainty	Sources	Examples
Scenario Uncertainty	Descriptive errors	Incorrect or insufficient information
	Aggregation errors	Spatial or temporal approximations
	Judgment errors	Selection of an incorrect model
	Incomplete analysis	Overlooking an important pathway
Parameter Uncertainty	Measurement errors	Imprecise or biased measurements
	Sampling errors	Small or unrepresentative samples
	Variability	In time, space or activities
	Surrogate data	Structurally-related chemicals
Model Uncertainty	Relationship errors	Incorrect inference on the basis for correlations
	Modeling errors	Excluding relevant variables

sophistication, data quality, and amenability to quantitative expressions of variability or uncertainty.

According to the U.S. EPA (1992), uncertainty characterization and uncertainty assessment are two ways of describing uncertainty at different degrees of sophistication. Uncertainty characterization usually involves a qualitative discussion of the thought processes used to select or reject specific data, estimates, scenarios, etc. Uncertainty assessment is a more quantitative process that may range from simpler measures (e.g., ranges) and simpler analytical techniques (e.g., sensitivity analysis) to more complex measures and techniques. Its goal is to provide decision makers with information concerning the quality of an assessment, including the potential variability in the estimated exposures, major data gaps, and the effect that these data gaps have on the exposure estimates developed.

A distinction between variability and uncertainty was made in Section 2.1. Although the quantitative process mentioned above applies more directly to variability and the qualitative approach more so to uncertainty, there is some degree of overlap. In general, either method provides the assessor or decision-maker with insights to better evaluate the assessment in the context of available data and assumptions. The following paragraphs describe some of the more common procedures for analyzing variability and uncertainty in exposure assessments. Principles that pertain to presenting the results of variability/uncertainty analysis are discussed in the next section.

Several approaches can be used to characterize uncertainty in parameter values. When uncertainty is high, the assessor may use order-of-magnitude bounding estimates of parameter ranges (e.g., from 0.1 to 10 liters for daily water intake). Another method describes the range for each parameter including the lower and upper bounds as well as a "best estimate" (e.g., 1.4 liters per day) determined by available data or professional judgement.

When sensitivity analysis indicates that a parameter profoundly influences exposure estimates, the assessor should develop a probabilistic description of its range. If there are enough data to support their use, standard statistical methods are preferred. If the data are inadequate, expert judgment can be used to generate a subjective probabilistic representation. Such judgments should be developed in a consistent, well-documented manner. Morgan and Henrion (1990) and Rish (1988) describe techniques to solicit expert judgment.

Most approaches to quantitative analysis examine how variability and uncertainty in values of specific parameters translate into the overall uncertainty of the assessment. Details may be found in reviews such as Cox and Baybutt (1981), Whitmore (1985), Inman and Helton (1988), Seller (1987), and Rish and Marnicio (1988). These approaches can generally be described (in order of increasing complexity and data needs) as: (1) sensitivity analysis; (2) analytical uncertainty propagation; (3) probabilistic uncertainty analysis; or (4) classical

statistical methods (U.S. EPA 1992). The four approaches are summarized in Table 2-3.

Table 2-3. Approaches to Quantitative Analysis of Uncertainty

Approach	Description	Example
Sensitivity Analysis	Changing one input variable at a time while leaving others constant, to examine effect on output	Fix each input at lower (then upper) bound while holding others at nominal values (e.g., medians)
Analytical Uncertainty Propagation	Examining how uncertainty in individual parameters affects the overall uncertainty of the exposure assessment	Analytically or numerically obtain a partial derivative of the exposure equation with respect to each input parameter
Probabilistic Uncertainty Analysis	Varying each of the input variables over various values of their respective probability distributions	Assign probability density function to each parameter; randomly sample values from each distribution and insert them in the exposure equation (Monte Carlo)
Classical Statistical Methods	Estimating the population exposure distribution directly, based on measured values from a representative sample	Compute confidence interval estimates for various percentiles of the exposure distribution

2.7. PRESENTING RESULTS OF VARIABILITY AND UNCERTAINTY ANALYSIS

Comprehensive qualitative analysis and rigorous quantitative analysis are of little value for use in the decision-making process, if their results are not clearly presented. In this chapter, variability (the receipt of different levels of exposure by different individuals) has been distinguished from uncertainty (the lack of knowledge about the correct value for a specific exposure measure or estimate). Most of the data that are presented in this handbook deal with variability directly, through inclusion of statistics that pertain to the distributions for various exposure factors.

Not all approaches historically used to construct measures or estimates of exposure have attempted to distinguish between variability and uncertainty. The assessor is advised to use a variety of exposure descriptors, and where possible, the full population distribution, when presenting the results. This information will provide risk managers with a better understanding of how exposures are distributed over the population and how variability in population activities influences this distribution.

Although incomplete analysis is essentially unquantifiable as a source of uncertainty, it should not be ignored. At a minimum, the assessor should describe the rationale for excluding particular 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 credible upper limits on exposure by way of a series of "what if" questions.

Although assessors have always used descriptors to communicate the kind of scenario being addressed, the 1992 Exposure Guidelines establish clear quantitative definitions for these risk descriptors. These definitions were established to ensure that consistent terminology is used throughout the Agency. The risk descriptors defined in the Guidelines include descriptors of individual risk and population risk. Individual risk descriptors are intended to address questions dealing with risks borne by individuals within a population, including not only measures of central tendency (e.g., average or median), but also those risks at the high end of the distribution. Population risk descriptors refer to an assessment of the extent of harm to the population being addressed. It can be either an estimate of the number of cases of a particular effect that might occur in a population (or population segment), or a description of what fraction of the population receives exposures, doses, or risks greater than a specified value. The data presented in the Exposure Factors Handbook is one of the tools available to exposure assessors to construct the various risk descriptors.

However, it is not sufficient to merely present the results using different exposure descriptors. Risk managers should also be presented with an analysis of the

uncertainties surrounding these descriptors. Uncertainty may be presented using simple or very sophisticated techniques, depending on the requirements of the assessment and the amount of data available. It is beyond the scope of this handbook to discuss the mechanics of uncertainty analysis in detail. At a minimum, the assessor should address uncertainty qualitatively by answering questions such as:

- What is the basis or rationale for selecting these assumptions/parameters, such as data, modeling, scientific judgment, Agency policy, "what if" considerations, etc.?

- What is the range or variability of the key parameters? How were the parameter values selected for use in the assessment? Were average, median, or upper-percentile values chosen? If other choices had been made, how would the results have differed?

- What is the assessor's confidence (including qualitative confidence aspects) in the key parameters and the overall assessment? What are the quality and the extent of the data base(s) supporting the selection of the chosen values?

Any exposure estimate developed by an assessor will have associated assumptions about the setting, chemical, population characteristics, and how contact with the chemical occurs through various exposure routes and pathways. The exposure assessor will need to examine many sources of information that bear either directly or indirectly on these components of the exposure assessment. In addition, the assessor will be required 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 also should qualitatively describe the rationale for selection of any conceptual or mathematical models that may have been used. 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.

Table 2-2 summarizes the three types of uncertainty, associated sources, and examples. Table 2-3 summarizes four approaches to analyze uncertainty quantitatively. These are described further in the 1992 Exposure Guidelines.

2.8. REFERENCES FOR CHAPTER 2

Bogen, K.T. (1990) Uncertainty in environmental health risk assessment. Garland Publishing, New York, NY.

Cox, D.C.; Baybutt, P.C. (1981) Methods for uncertainty analysis. A comparative survey. Risk Anal. 1(4):251-258.

Duan, N. (1982) Microenvironment types: A model for human exposure to air pollution. Environ. Intl. 8:305-309.

Inman, R.L.; Helton, J.C. (1988) An investigation of uncertainty and sensitivity analysis techniques for computer models. Risk Anal. 8(1):71-91.

Morgan, M.G.; Henrion, M. (1990) Uncertainty: A guide to dealing with uncertainty in quantitative risk and policy analysis. Cambridge University Press, New York, NY.

National Research Council (NRC). (1994) Science and judgment in risk assessment. National Academy Press, Washington, DC.

Rish, W.R. (1988) Approach to uncertainty in risk analysis. Oak Ridge National Laboratory. ORNL/TM-10746.

Rish, W.R.; Marnicio, R.J. (1988) Review of studies related to uncertainty in risk analysis. Oak Ridge National Laboratory. ORNL/TM-10776.

Seller, F.A. (1987) Error propagation for large errors. Risk Anal. 7(4):509-518.

U.S. EPA (1992) Guidelines for exposure assessment. Washington, DC: Office of Research and Development, Office of Health and Environmental Assessment. EPA/600/Z-92/001.

U.S. EPA (1995) Guidance for risk characterization. Science Policy Council, Washington, DC.

Whitmore, R.W. (1985) Methodology for characterization of uncertainty in exposure assessments. EPA/600/8-86/009.

3. DRINKING WATER INTAKE

3.1. BACKGROUND

Drinking water is a potential source of human exposure to toxic substances. Contamination of drinking water may occur by, for example, percolation of toxics through the soil to ground water that is used as a source of drinking water, runoff or discharge to surface water that is used as a source of drinking water; intentional or unintentional addition of substances to treat water (e.g., chlorination); and leaching of materials from plumbing systems (e.g., lead). Estimating the magnitude of the potential dose of toxics from drinking water requires information on the quantity of water consumed. The purpose of this section is to describe key published studies that provide information on drinking water consumption (Section 3.2) and to provide recommendations of consumption rate values that should be used in exposure assessments (Section 3.6).

Currently, the U.S. EPA uses the quantity of 2 L per day for adults and 1 L per day for infants (individuals of 10 kg body mass or less) as default drinking water intake rates (U.S. EPA, 1980, 1991). These rates include drinking water consumed in the form of juices and other beverages containing tapwater (e.g., coffee). The National Academy of Sciences (NAS, 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 some individuals in physically-demanding occupations or living in warmer regions may have high levels of water intake.

Numerous studies cited in this chapter have generated data on drinking water intake rates. In general, these sources support EPA's use of 2 L/day for adults and 1 L/day for children as upper-percentile tapwater intake rates. Many of the studies have reported fluid intake rates for both total fluids and tapwater. *Total fluid intake* is defined as consumption of all types of fluids including tapwater, milk, soft drinks, alcoholic beverages, and water intrinsic to purchased foods. *Total tapwater* is defined as water consumed directly from the tap as a beverage or used in the preparation of foods and beverages (i.e., coffee, tea, frozen juices, soups, etc.). Data for both consumption categories are presented in the sections that follow. However, for the purposes of exposure assessments involving source-specific contaminated drinking water, intake rates based on total tapwater are more representative of source-specific tapwater intake. Given the assumption that purchased foods and beverages are widely distributed and less likely to contain source-specific water, the use of total fluid intake rates may overestimate the potential exposure to toxic substances present only in local water supplies; therefore tapwater intake, rather than total fluid intake, is emphasized in this section.

All studies on drinking water intake that are currently available are based on short-term survey data. Although short-term data may be suitable for obtaining mean intake values that are representative of both short- and long-term consumption patterns, upper-percentile values may be different for short-term and long-term data because more variability generally occurs in short-term surveys. It should also be noted that most drinking water surveys currently available are based on recall. This may be a source of uncertainty in the estimated intake rates because of the subjective nature of this type of survey technique.

The distribution of water intakes is usually, but not always, lognormal. Instead of presenting only the lognormal parameters, the actual percentile distributions are presented in this handbook, usually with a comment on whether or not it is lognormal. To facilitate comparisons between studies, the mean and the 90th percentiles are given for all studies where the distribution data are available. With these two parameters, along with information about which distribution is being followed, one can calculate, using standard formulas, the geometric mean and geometric standard deviation and hence any desired percentile of the distribution. Before doing such a calculation one must be sure that one of these distributions adequately fits the data.

The available studies on drinking water consumption are summarized in the following sections. They have been classified as either key studies or relevant studies based on the applicability of their survey designs to exposure assessment of the entire United States population. Recommended intake rates are based on the results of key studies, but relevant studies are also presented to provide the reader with added perspective on the current state-of-knowledge pertaining to drinking water intake.

3.2. KEY GENERAL POPULATION STUDIES ON DRINKING WATER INTAKE

Canada Department of Health and Welfare (1981) - Tapwater Consumption in Canada - In a study conducted by the Canadian Department of Health and Welfare, 970 individuals from 295 households were surveyed to determine the per capita total tapwater 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 tapwater 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 tapwater consumed at home and tapwater consumed away from home. The survey also did not attempt to estimate intake rates for fluids other than tapwater. Consequently, no intake rates for total fluids were reported.

Daily consumption distribution patterns for various age groups are presented in Table 3-1. For adults (over 18 years of age) only, the average total tapwater 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. The intake data for males, females, and both sexes combined as a function of age and expressed in the units of milliliters (grams) per kilogram body weight are presented in Table 3-2. The tapwater 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. Intake rates for specific age groups and seasons are presented in Table 3-3. The average daily total tapwater intake rates 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

Table 3-1. Daily Total Tapwater Intake Distribution for Canadians, by Age Group (approx. 0.20 L increments, both sexes, combined seasons)

Amount Consumed[a]	Age Group (years) 5 and under		6-17		18 and over	
L/day	%	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 tapwater and foods and beverages derived from tapwater.
Source: Canadian Ministry of National Health and Welfare, 1981.

speculate that the reason for the small seasonal variation here is that in Canada, even in the summer, the ambient temperature seldom exceeded 20 degrees 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 degrees. Average daily total tapwater intake rates as a function of the level of physical activity, as estimated subjectively, are presented in Table 3-4. The amounts of tapwater consumed that are derived from various foods and beverages are presented in Table 3-5. Note that the consumption of direct "raw" tapwater is almost constant across all age groups from school-age children through the oldest ages. The increase in total tapwater consumption beyond school age is due to coffee and tea consumption.

Table 3-2 Average Daily Tapwater Intake of Canadians (expressed as milliliters per kilogram body weight)

	Average Daily Intake (ml/kg)		
Age Group (years)	Females	Males	Both Sexes
<3	53	38	45
3-5	49	48	48
6-17	24	27	26
18-34	23	19	21
35-54	25	19	22
55+	24	21	22
Total Population	24	21	22

Source: Canadian Ministry of National Health and Welfare 1981

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

	Age (years)						
	<3	3-5	6-17	18-34	35-54	<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	1.50	1.50	2.21	2.57	2.57	2.29	2.36

[a] Includes tapwater and foods and beverages derived from tapwater

Source: Canadian Ministry of National Health and Welfare 1981

Table 3-4 Average Daily Total Tapwater 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	69	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	1.30	16	1.35	26
Did Not State	1.30	45	1.31	26
TOTAL		668		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 tapwater and foods and beverages derived from tapwater

Source: Canadian Ministry of National Health and Welfare 1981

Table 3-5. Average Daily Tapwater Intake by Canadians, Apportioned Among Various Beverages (both sexes, by age, combined seasons, L/day)[a]

	Age Group (years)					
	Under 3	3-5	6-17	18-34	35-54	55 and Over
Total Number in Group 34	47	250	232	284	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	0.50	0.42
"Other Type of Drink"	0.21	0.34	0.34	0.20	0.14	0.11
Reconstituted Milk	0.10	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 tapwater and foods and beverages derived from tapwater.
* Less than 0.01 L/day

Source: Canadian Ministry of National Health and Welfare, 1981

Data concerning the source of tapwater (municipal, well, or lake) was presented in one table of the study. This categorization is not appropriate for making conclusions about consumption of ground versus surface water.

This survey may be more representative of total tapwater consumption than some other less comprehensive surveys because it included data for some tapwater-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 tapwater 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 tapwater intakes; the largest regional difference was between Ontario (1.18 liters/day) and Quebec (1.55 liters/day).

Ershow and Cantor (1989) - Total Water and Tapwater Intake in the United States: Population-Based Estimates of Quantities and Sources - Ershow and Cantor (1989) estimated water intake rates based on data collected by the USDA 1977-1978 Nationwide Food Consumption Survey (NFCS). Daily intake rates for tapwater and total water were calculated for various age groups for males, females, and both sexes combined. Tapwater 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 tapwater 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.

Daily total tapwater intake rates, expressed as mL (grams) per day by age group are presented in Table 3-6. These data follow a lognormal distribution. The same data, expressed as mL (grams) per kg body weight per day are presented in Table 3-7. 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, is presented in Table 3-8. 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 1,190 mL/day and 2,090 mL/day. Note that older adults have greater intakes than do adults between age 20 and

Table 3-6 Total Tap water Intake (mL/day) for Both Sexes Combined[a]

Age (years)	Number of Observations	Mean	SD	S.E. 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 - 0.9	221	328	265	18	*	0	0	117	268	480	658	764	*
1 - 3	1498	635	390	10	33	109	240	374	567	820	1162	1419	1899
4 - 6	1702	742	406	10	68	204	303	459	660	972	1392	1520	1932
7 - 10	2405	787	417	9	68	241	318	484	731	1016	1338	1556	1998
11 - 14	2803	925	521	10	76	244	360	561	838	1196	1621	1924	2503
15 - 19	2978	999	533	11	55	239	348	587	897	1294	1763	2134	2872
20 - 44	7171	1253	709	8	105	337	483	766	1144	1610	2121	2559	3634
45 - 64	4560	1546	723	11	335	591	745	1057	1439	1878	2451	2870	3704
65 - 74	1663	1500	660	16	301	611	766	1044	1394	1873	2333	2603	3479
75+	878	1381	640	20	279	568	728	961	1302	1706	2170	2476	3487
Infants (ages < 1)	403	302	258	13	0	0	0	113	240	424	649	775	1102
Children (ages 1-10)	5665	736	410	5	56	192	286	442	665	960	1294	1516	1951
Teens (ages 11-19)	5801	965	562	7	67	240	353	574	867	1245	1703	2026	2748
Adults (ages 20-64)	11731	1366	728	7	145	416	559	870	1252	1737	2268	2707	3780
Adults (ages 65+)	2541	1459	643	13	279	598	751	1019	1367	1806	2287	2636	3338
All	20981	1193	702	4	80	286	423	690	1081	1561	2092	2477	3415

[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

Source: Ershow and Cantor, 1989.

Table 3-7. Total Tapwater Intake (mL/kg day) for Both Sexes Combined[a]

Age (years)	Number of Observations: Actual Count	Number of Observations: Weighted Count	Mean	SD	S.E. of Mean	1	5	10	25	50	75	90	95	99
<0.5	182	201.2	52.4	53.2	3.9	*	0.0	0.0	14.8	37.8	66.1	128.3	155.6	*
0.5-0.9	221	243.2	36.2	29.2	2.0	*	0.0	0.0	15.3	32.2	48.1	69.4	102.9	*
1-3	1498	1687.7	46.8	28.1	0.7	2.7	11.8	17.8	27.2	41.4	60.4	82.1	101.6	143.6
4-6	1702	1923.9	37.9	21.8	0.5	3.4	10.3	14.9	21.9	33.3	48.7	69.3	81.1	103.4
7-10	2405	2742.4	26.9	15.3	0.3	2.2	7.4	10.3	16.0	24.0	35.5	47.3	55.2	70.5
11-14	2803	3146.9	20.2	11.6	0.2	1.5	4.9	7.5	11.9	18.1	26.2	35.7	41.9	55.0
15-19	2908	3677.9	16.4	9.6	0.2	1.0	3.9	5.7	9.6	14.8	21.5	29.0	35.0	46.3
20-44	7171	13444.5	18.6	10.7	0.1	1.6	4.9	7.1	11.2	16.8	23.7	32.2	38.4	53.4
45-64	4560	8300.4	22.0	10.8	0.2	4.4	8.0	10.3	14.7	20.2	27.2	35.5	42.1	57.8
65-74	1663	2740.2	21.9	9.9	0.2	4.6	8.7	10.9	15.1	20.2	27.2	35.2	43.6	51.6
75+	878	1401.8	21.6	9.5	0.3	3.8	8.8	10.7	15.0	20.5	27.1	33.9	38.6	47.2
Infants (ages <1)	403	444.3	43.5	42.5	2.1	0.0	0.0	0.0	15.3	35.3	54.7	101.8	126.5	220.5
Children (ages 1-10)	5605	6354.1	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 11-19)	5801	6824.9	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 20-64)	11731	21744.9	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+)	2541	4142.0	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	26081	39510.2	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 tapwater 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.

Source: Ershow and Cantor, 1989.

Table 3-8 Summary of Tapwater 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 (1-10 years)	736	265-1,294	35.5	12.5 - 64.4
Teens (11-19 years)	965	353-1,701	18.2	6.5 - 32.3
Adults (20 -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)

65, 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).

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 tapwater intake (1,190 mL/day) is 55 percent of the total water intake. (The detailed intake data for various age groups are presented in Table 3-9). Ershow and Cantor (1989) also concluded that, for all age groups combined, the proportion of tapwater consumed as drinking water, foods, and beverages is 54 percent, 10 percent and 36 percent, respectively. (The detailed data on proportion of tapwater consumed for various age groups are presented in Table 3-10). Ershow and Cantor (1989) also observed that males of all age groups had higher total water and tapwater consumption rates than females; the variation of each from the combined-sexes mean was about 8 percent.

Ershow and Cantor (1989) also presented data on total water intake and tapwater intake for children of various ages. They found, for infants and children between the ages of 6 months and 15 years, that the total water intake per unit body weight increased smoothly and sharply from 30 mL/kg-day above age 15 years to 190 mL/kg-day for ages less than 6 months. This probably represents metabolic requirements for water as a dietary constituent. However, they found that the intake of tapwater alone went up only slightly with decreasing age (from 20 to 45 mL/kg-day as age decreases from 11 years to less than 6 months). Ershow and Cantor (1989) attributed this small effect of age on tapwater intake to the large number of alternative water sources (besides tapwater) used for the younger age groups.

Table 3-9 Total Tapwater Intake (as percent of total water intake) by Broad Age Categories[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
1-10	45	6	19	24	34	45	57	67	72	81
11-19	47	6	18	24	35	47	59	69	74	83
20-64	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 tapwater 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 percent.

Source: Ershow and Cantor 1989

Table 3-10. General Dietary Sources of Tapwater for Both Sexes[a,b]

Age (years)	Source	% of Tapwater							
		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							
1-10	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							
11-19	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							
20-64	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 percent.
Source: Ershow and Cantor, 1989

With respect to region of the country, the northeast states had slightly lower average tapwater 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 United States population with respect to age distribution, sex, racial composition, and residential location. It is therefore suitable as a description of national tapwater consumption. The chief limitation of the study is that the data were collected in 1978 and do not reflect the expected increase in the consumption of soft drinks and bottled water or changes in the diet within the last two decades. Since the data were collected for only a three-day period, the extrapolation to chronic intake is uncertain.

Roseberry and Burmaster (1992) - Lognormal Distributions for Water Intake - Roseberry and Burmaster (1992) fit lognormal distributions to the water intake data reported by Ershow and Cantor (1989) and estimated population-wide distributions for total fluid and total tapwater intake based on proportions of the population in each age group. Their publication shows the data and the fitted log-normal distributions graphically. The mean

was estimated as the zero intercept, and the standard deviation 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. Summary statistics for the best-fit lognormal distribution are presented in Table 3-11. In this table, the simulated balanced population represents an adjustment to account for the different age distribution of the United States population in 1988 from the age distribution in 1978 when Ershow and Cantor (1989) collected their data. Table 3-12 summarizes the quantiles and means of tapwater intake as estimated from the best-fit distributions. The mean total tapwater intake rates for the two adult populations (age 20 to 65 years, and 65+ years) were estimated to be 1.27 and 1.34 L/day.

Table 3-11. Summary Statistics for Best-Fit Lognormal Distributions for Water Intake Rates[a]

Group (age in years)	ln Total Fluid Intake Rate μ	σ	R^2
0 < age < 1	6.979	0.291	0.996
1 ≤ age < 11	7.182	0.340	0.953
11 ≤ age < 20	7.490	0.347	0.966
20 ≤ age < 65	7.563	0.400	0.977
65 ≤ age	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)	ln Total Tapwater Intake μ	σ	R^2
0 < age < 1	5.587	0.615	0.970
1 ≤ age < 11	6.429	0.498	0.984
11 ≤ age < 20	6.667	0.535	0.986
20 ≤ age < 65	7.023	0.489	0.956
65 ≤ age	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 tapwater intake shown in Tables 3-12.

97.5 percentile intake rate = $\exp[\mu + (1.96 \cdot \sigma)]$
75 percentile intake rate = $\exp[\mu + (0.6745 \cdot \sigma)]$
50 percentile intake rate = $\exp[\mu]$
25 percentile intake rate = $\exp[\mu - (0.6745 \cdot \sigma)]$
2.5 percentile intake rate = $\exp[\mu - (1.96 \cdot \sigma)]$
Mean intake rate = $\exp[\mu + 0.5 \cdot \sigma^2)]$
Source: Roseberry and Burmaster, 1992.

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. RELEVANT GENERAL POPULATION STUDIES ON DRINKING WATER INTAKE

National Academy of Sciences (1977) - Drinking Water and Health - NAS (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: Evans (1941); Bourne and Kidder (1953); Walker et al. (1957); Wolf (1958); Guyton (1968); McNall and Schlegel (1968); Randall (1973); NAS (1974); and Pike and Brown (1975). Although the calculated average intake rate was 1.63 L per day, NAS (1977) adopted a larger rate (2 L per day) to represent the intake of the majority of water consumers. This value is relatively consistent with the total tapwater intakes rate estimated from the key studies 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 tapwater intake rates and this study is not considered a key study.

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 tapwater taken at home and away from home; purchased alcoholic beverages; and non-tapwater-based drinks. Total tapwater included water content of tea, coffee, and other hot water drinks; homemade alcoholic beverages; and tapwater consumed directly as a beverage. The assumed tapwater contents for these beverages are presented in Table 3-13. 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). These data are listed in Table 3-14. The mean per capita total liquid intake rate for all individuals surveyed was 1.59 L/day, and the mean per capita total tapwater intake rate was 0.95 L/day, with a 90th percentile

Table 3-12. Estimated Quantiles and Means for Total Tapwater Intake Rates (mL/day)[a]

Age Group (years)	Percentile 2.5	25	50	75	97.5	Arithmetic Average
0 < age < 1	80	176	267	404	891	323
1 ≤ age < 11	233	443	620	867	1,644	701
11 ≤ age < 20	275	548	786	1,128	2,243	907
20 ≤ age < 65	430	807	1,122	1,561	2,926	1,265
65 ≤ age	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 tapwater 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 3-13. Assumed Tapwater Content of Beverages

Beverage	% Tapwater
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 1[b]	0
Fruit Juice 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

value of about 1.3 L/day (which is the value of the percentile for the home tapwater alone in Table 3-14). Liquid intake rates were also estimated for males and females in various age groups. Table 3-15 summarizes the total liquid and total tapwater 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 tapwater 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 3-15. This calculation assumes, as does Table 3-14 and 3-15, that the underlying distribution is normal and not lognormal.

The advantage of using 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. Also, the use of total liquid and total tapwater was well defined in this study. However, the relatively short-term nature of the survey make extrapolation to long-term consumption patterns difficult. 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 socio-economic factors. For these reasons this study is not considered a key study in this document.

International Commission on Radiological Protection (ICRP) (1981) - Report to the Task Group on Reference Man - Data on fluid intake levels have also been summarized by the International Commission on Radiological Protection (ICRP) in the Report of the Task Group on Reference Man (ICRP, 1981). These intake levels for adults and children are summarized in Table 3-16. The amount of drinking water (tapwater and water-based drinks) consumed by adults ranged from about 0.37 L/day to about 2.18 L/day under "normal" conditions. The levels for children ranged from 0.54 to 0.79 L/day. Because the populations, survey design, and intake categories are not clearly defined, this study has limited usefulness in developing recommended intake rates for use in exposure assessment. It is reported here as a relevant study because the findings, although poorly defined, are consistent with the results of other studies.

Table 3-14. Intake of Total Liquid, Total Tapwater, and Various Beverages (L/day)

Beverage	All Individuals					Consumers Only			
	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	0.31-4.50	100.0	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	100.0	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 Tapwater	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 Tapwater 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 Tapwater 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	0.190	0.0059	0.178-0.202	0.00-0.56	0.00-1.27	63.0	0.302	0.0105	0.281-0.323
Other Hot Water Drinks	0.011	0.0015	0.008-0.014	0.00-0.01	0.00-0.25	9.2	0.120	0.0133	0.093-0.147
Cold Water	0.103	0.0049	0.093-0.113	0.00-0.31	0.01-0.85	51.0	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 Tapwater	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 Ices	0.010	0.0017	0.007-0.013	0.00-0.00	0.00-0.20	7.0	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	0.0250	0.424-0.524

[a] Consumers only is defined as only those individuals who reported consuming the beverage during the survey period.
Source: Hogan and Ellis, 1980

Table 3-15. Summary of Total Liquid and Total Tapwater Intake for Males and Females (L/day)

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	1-4	88	75	0.853	0.858	0.0557	0.0660	0.742-0.964	0.756-1.020	0.38-1.51	0.39-1.48
	5-11	249	201	0.936	0.902	0.0296	0.0306	0.917-1.015	0.841-0.963	0.54-1.48	0.51-1.39
	12-17	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
	18-30	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
	31-54	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	1.830	1.482	0.0498	0.0356	1.730-1.930	1.411-1.553	1.03-2.77	0.84-2.17
Total Tapwater Intake	1-4	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
	5-11	249	201	0.550	0.533	0.0223	0.0239	0.505-0.595	0.485-0.581	0.22-0.90	0.22-0.93
	12-17	180	169	0.865	0.725	0.0372	0.0328	0.731-0.8790	0.659-0.791	0.29-1.35	0.31-1.16
	18-30	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
	31-54	512	551	1.201	1.091	0.0309	0.0240	1.139-1.263	1.043-1.139	0.64-1.88	0.62-1.68
	55+	396	454	1.133	1.027	0.0337	0.0273	1.064-1.202	0.972-1.082	0.62-1.72	0.54-1.57

Source: Hoylin and Ellis, 1980.

Table 3-16. Measured Fluid Intakes (mL/day)

Subject	Total Fluids	Milk	Tapwater	Water-Based Drinks[a]
Adults ("normal" conditions)[b]	1000-2400	120-450	45-730	320-1450
Adults (high environmental temperature to 32°C)	2840-3410 3256 ± SD = 900			
Adults (moderately active)	3700			
Children (5-14 yr)	1000-1200 1310-1670	330-500 540-650	ca. 200 540-700	ca. 380

[a] Includes tea, coffee, soft drinks, beer, cider, wine, etc.
[b] "Normal" conditions refer to typical environmental temperature and activity levels.
Source: ICRP, 1981

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 tapwater 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 tapwater intake rate (1.26 L/day) was very similar to the mean intake rate (Gillies and Paulin, 1983). The reported range was 0.26 to 2.80 L/day.

The advantage of these data are that they were generated using duplicate sampling techniques. Because this approach is more objective than recall methods, it may result in more accurate response. 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.

Pennington (1983) - Revision of the Total Diet Study Food List and Diets - Based on data from the U.S. Food and Drug Administration's (FDA'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 U.S. Department of Agriculture (USDA) Nationwide Food Consumption Survey (NFCS) and 24-hour recall data from the Second National Health and Nutrition Examination Survey (NHANES II). The number of participants in NFCS and NHANES II was approximately 30,000 and 20,000, respectively. The diets were developed to "approximate 90 percent or more of the weight of the foods usually consumed" (Pennington, 1983). The source of water (bottled water as distinguished from tapwater) 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 percent water, and juices were assumed to contain 75 percent 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. These intake rates are presented in Table 3-17. 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 tapwater intake per se, as distinguished from bottled

water. For this reason, it is not considered a key tapwater study in this document.

Table 3-17. Intake Rates of Total Fluids and Total Tapwater by Age Group

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

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 1977-78 NFCS, U.S. EPA (1984) determined daily food and beverage intake levels by age to be used in assessing radionuclide intake through food consumption. Tapwater, water-based drinks, and soups were identified subcategories of the total beverage category. Daily intake rates for tapwater, water-based drinks, soup, and total beverage are presented in Table 3-18. As seen in Table 3-18, mean tapwater 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 0.03 to 0.06 L/day, and mean total beverage intake levels ranged from 1.48 to 1.73 L/day. Total tapwater intake rates were estimated by combining the average daily intakes of tapwater, water-based drinks, and soups for each age group. For adults (ages 20 years and older), mean total tapwater 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. These intake rates do not include reconstituted infant formula. The total tapwater intake rates, derived by combining data on tapwater, 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. These intake rates are based on the same USDA NFCS data used in Ershow and Cantor (1989). Therefore, the data limitations discussed previously also apply to this study.

Cantor et al. (1987) - Bladder Cancer, Drinknig Water Source, and Tapwater Consumption - The National Cancer Institute (NCI), 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

Table 3-18. Mean and Standard Error for the Daily Intake of Beverages and Tapwater by Age

Age (years)	Tapwater 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	1434.0 ± 13.7
Under 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	1025.0 ± 34.2
15 to 19	664.7 ± 26.0	201.5 ± 17.7	34.8 ± 3.2	1241.0 ± 35.9
20 to 24	656.4 ± 33.9	343.1 ± 23.1	38.9 ± 4.2	1484.0 ± 46.9
25 to 29	619.8 ± 34.6	441.6 ± 23.6	41.3 ± 4.2	1531.0 ± 48.0
30 to 39	636.5 ± 27.2	601.0 ± 18.6	40.6 ± 3.3	1642.0 ± 37.7
40 to 59	735.3 ± 21.1	686.5 ± 14.4	51.6 ± 2.6	1732.0 ± 29.3
60 and over	762.5 ± 23.7	561.1 ± 16.2	59.4 ± 2.9	1547.0 ± 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 tapwater 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.

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 tapwater 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 tapwater; and 2) beverages from other sources. Tapwater 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, had no people under the age of 21 years and 57 percent 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 tapwater intake rates for a "typical" week were compiled by sex, age group, and geographic region. These rates are listed in Table 3-19. The average total fluid intake rate was 2.01 L/day for men of which 70 percent (1.4 L/day) was derived from tapwater, and 1.72 L/day for women of which 79 percent (1.35 L/day) was derived from tapwater. Frequency distribution data for the 5,081 controls, for which the authors had information on both tapwater consumption and cigarette smoking habits, are presented in Table 3-20. 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 3-20 after plotting it on log probability graph paper. These values represent the usual level of intake for this population of adults in the winter.

A limitation associated with this data set is 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 from the winter previous to the interview. Extrapolation to other seasons and intake durations is difficult.

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

Table 3-19. Average Total Tapwater Intake Rate by Sex, Age, and Geographic Area

Group/Subgroup	Number of Respondents	Average Total Tapwater Intake,[a,b] L/day
Total group	5,258	1.39
Sex		
Males	3,892	1.40
Females	1,366	1.35
Age, years		
21-44	291	1.30
45-64	1,991	1.48
65-84	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 tapwater defined as all water and beverages derived from tapwater.

Source: Cantor et al., 1987.

Table 3-20. Frequency Distribution of Total Tapwater 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
2.96	18.1	100.0

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

Source: Cantor, et al., 1987.

AIHC (1994) - Exposure Factors Handbook - The Exposure Factors Sourcebook (AIHC, 1994) presented

drinking water intake rate recommendations for adults. Although AIHC (1994) provided little information on the studies used to derive mean and upper percentile recommendations, the references indicate that several of the studies used were the same as ones categorized as relevant studies in this handbook. The mean adult drinking water recommendations in AIHC (1994) and this handbook are in agreement. However, the upper percentile value recommended by AIHC (1994) (2.0 L/day) is slightly lower than that recommended by this handbook (2.4 L/day). Based on data provided by Ershow and Cantor (1989), 2.0 L/day corresponds to only approximately the 84th percentile of the drinking water intake rate distribution. Thus, a slightly higher value is appropriate for representing the upper percentile (i.e., 90 to 95th percentile) of the distribution. AIHC (1994) also presents simulated distributions of drinking water intake based on Roseberry and Burmaster (1992). These distributions are also described in detail in Section 3.2 of this handbook. AIHC (1994) has been classified as a relevant rather than a key study because it is not the primary source for the data used to make recommendations for this document.

USDA (1995) - Food and Nutrient Intakes by Individuals in the United States, 1 Day, 1989-91. - USDA (1995) collected data on the quantity of "plain drinking water" and various other beverages consumed by individuals in 1 day during 1989 through 1991. The data were collected as part of USDA's Continuing Survey of Food Intakes by Individuals (CSFII). The data used to estimate mean per capita intake rates combined one-day dietary recall data from 3 survey years: 1989, 1990, and 1991 during which 15,128 individuals supplied one-day intake data. Individuals from all income levels in the 48 conterminous states and Washington D.C. were included in the sample. A complex three-stage sampling design was employed and the overall response rate for the study was 58 percent. 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. The intake rates based on this study are presented in Table 3-21. Table 3-21 includes data for: a) "plain drinking water", which might be assumed to mean

Table 3-21 Mean Per Capita Drinking Water Intake Based on USDA, CSFII Data From 1989-91 (mL/day)

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

* 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

tapwater directly consumed rather than bottled water; b) coffee and tea, which might be assumed to be constituted from tapwater; and 3) fruit drinks and ades, which might be assumed to be reconstituted from tapwater rather than canned products; and 4) 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 "tapwater" does not occur, and this uncertainty prevents the use of this study as a key study of tapwater intake.

The advantages of using these data are that: 1) the survey had a large sample size; 2) the authors attempted to represent the general United States population by oversampling low-income groups and by weighting the data to compensate for low response rates; and 3) it reflects more recent intake data than the key studies. The disadvantages are that: 1) the response rate was low; 2) the word "tapwater" was not defined and the assumptions that must be used in order to compare the data with the other tapwater studies might not be valid; 3) the data collection period reflects only a one-day intake period, and may not reflect long-term drinking water intake patterns; and 4) data on the percentiles of the distribution of intakes were not given.

Tsang and Klepeis (1996) - National Human Activity Pattern Survey (NHAPS) - The U.S. EPA collected information on the number of glasses of drinking water and juice reconstituted with tapwater consumed by the general population as part of the National Human Activity Pattern Survey (Tsang and Klepeis, 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 of the number of 8-ounce glasses of water and the number of 8-ounce glasses of juice reconstituted with water than they drank during the 24-hour survey period (Tables 3-22 and 3-23). The median number of glasses of tapwater consumed was 1-2 and the median number of glasses of juice with tapwater consumed was 1-2.

For both individuals who drank tapwater and individuals who drank juices reconstituted with tapwater, the number of glasses ranged from 1 to 20. The highest percentage of the population (37.1 percent) who drank tapwater consumed 3-5 glasses and the highest percentage of the population (51.5 percent) who consumed juice reconstituted with tapwater drank 1-2 glasses. Based on the assumption that each glass contained 8 ounces of water (226.4 mL), the total volume of tapwater and juice with tapwater consumed would range from 0.23 L/day (1 glass) to 4.5 L/day (20 glasses) for respondents who drank tapwater. Using the same assumption, the volume of tapwater 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 tapwater consumed for the population who consumed 1-2 glasses would be 0.23 L/day to 0.46 L/day. Assuming that the average individual consumes 3-5 glasses of tapwater plus 1-2 glasses of juice with tapwater, the range of total tapwater 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 is 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 tapwater consumed. However, 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.

3.4. PREGNANT AND LACTATING WOMEN

Ershow et al. (1991) - Intake of Tapwater and Total Water by Pregnant and Lactating Women - Ershow et al. (1991) used data from the 1977-78 USDA NFCS to estimate total fluid and total tapwater 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. "Tapwater" included tapwater consumed directly as a beverage and tapwater used to prepare food and tapwater-based beverages. "Total water" was defined as all water from tapwater and non-tapwater sources, including water contained in food. Estimated total fluid and total tapwater intake rates for the three groups are

Table 3-22 Number of Respondents that Consumed Tapwater 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	1,334	1,225	1,253	500	151	31	138
Gender								
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)								
1-4	263	114	96	40	7	1	0	5
5-11	348	90	127	86	15	7	2	20
12-17	326	86	109	88	22	7	•	11
18-64	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

NOTE: "•" = Missing Data
"DK" = Don't know
N = sample size
Refused = respondent refused to answer
Source: Tsang and Klepeis, 1996

Table 3-23. Number of Respondents that Consumed Juice Reconstituted with Tapwater 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
Gender								
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)								
1-4	263	126	71	48	11	4	1	2
5-11	348	123	140	58	12	2	1	11
12-17	326	112	118	63	18	7	1	4
18-64	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	25
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	25
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

NOTE: "*" = Missing Data
"DK" = Don't know
N = sample size
Refused = Respondent refused to answer
Source: Tsang and Klepeis, 1996

presented in Tables 3-24 and 3-25, 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 tapwater intake rate (1.31 L/day) than pregnant women (1.19 L/day) and control women (1.16 L/day). The tapwater distributions are neither normal nor lognormal, but lactating women had a higher mean tapwater 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 tapwater (1.24 L/day) than urban/suburban women (n=4,581, 1.93 and 1.13 L/day, respectively). Total water and tapwater 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 tapwater intake. Total tapwater intake accounted for over 50 percent of mean total fluid in all three groups of women (Table 3-25). Drinking water accounted for the largest single proportion of the total fluid intake for control (30 percent), pregnant (34 percent), and lactating women (30 percent) (Table 3-26). All other beverages combined accounted for approximately 46 percent, 43 percent, and 45 percent 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 (Section 3.2). A further advantage of this study is that it provides information on estimates of total waterand tapwater intake rates for pregnant and lactating women. This topic has rarely been addressed in the literature.

Table 3-24. Total Fluid Intake of Women 15–49 Years Old

Reproductive Status*	Mean	Standard Deviation	Percentile Distribution 5	10	25	50	75	90	95
mL/day									
Control	1940	686	995	1172	1467	1835	2305	2831	3186
Pregnant	2076	743	1085	1236	1553	1928	2444	3028	3475
Lactating	2242	658	1185	1434	1833	2164	2658	3169	3353
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

* Number of observations: nonpregnant, nonlactating controls (n = 6,201); pregnant (n = 188); lactating (n = 77).
Source: Ershow et al., 1991.

3.5. HIGH ACTIVITY LEVELS/HOT CLIMATES

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 pedal pedal-driven propeller fans for 8-hour work cycles under varying environmental conditions. The activity pattern for each individual was: cycled at 15 minute pedalling and 15 miute 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. The water intake rates obtained at the three different activity levels and the various environmental temperatures are presented in Table 3-27. The data

Table 3-25. Total Tapwater Intake of Women 15-49 Years Old

Reproductive Status[a]	Mean	Standard Deviation	Percentile Distribution 5	10	25	50	75	90	95
mL/day									
Control	1157	635	310	453	709	1065	1503	1983	2310
Pregnant	1189	699	274	419	713	1063	1501	2191	2424
Lactating	1310	591	430	612	855	1330	1693	1945	2191
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 tapwater (%)									
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: nonpregnant, nonlactating controls (n = 6,201); pregnant (n = 188); lactating (n = 77).
Source: Ershow et al., 1991.

Table 3-26 Total Fluid (mL/Day) Derived from Various Dietary Sources by Women Aged 15-49 Years[a]

Sources	Control Women Mean[b]	Percentile 50	Percentile 95	Pregnant Women Mean[b]	Percentile 50	Percentile 95	Lactating Women Mean[b]	Percentile 50	Percentile 95
Drinking Water	563	480	1440	695	640	1760	677	560	1600
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	99	65	257	98	69	246	119	82	387
Citrus and Noncitrus 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	1045	197	0	955	205	80	955
Carbonated Soft Drinks[c]	174	110	590	130	73	464	117	57	440
Noncarbonated 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	1940	NA	NA	2076	NA	NA	2242	NA	NA

[a] Number of observations: nonpregnant, nonlactating 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 noncalorie soft drinks
NA: Not appropriate to sum the columns for the 50th and 95th percentiles of intake.
Source: Ershow et al., 1991

Table 3-27. Water Intake at Various Activity Levels (L/hr)[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]	
	No.[d]	Intake	No.	Intake	No.	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 percent; air velocity = 60 ft/min.
[c] The symbol "hp" refers to horsepower.
[d] Number of subjects with continuous data.
Source: McNall and Schlegel, 1968

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.

United States 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 one 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 percent 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 tapwater. Planning factors have been established for hot, temperate, and cold climates based on the following mixture of activities among the work force: 15 percent of the force performing light work, 65 percent of the force performing medium work, and 20 percent 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. Drinking water consumption factors for these three climates are presented in Table 3-28. 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. RECOMMENDATIONS

The key studies described in this section were used in selecting recommended drinking water (tapwater) consumption rates for adults and children. The studies on other subpopulations were not classified as key versus relevant. Although different survey designs and populations were utilized by key and relevant studies described in this report, the mean and upper-percentile estimates reported in these studies are reasonably similar. The general design of both key and relevant studies and their limitations are summarized in Table 3-29. It should be noted that studies that surveyed large representative samples of the population provide more reliable estimates of intake rates for the general population. Most of the surveys described here are based on short-term recall which may be biased toward excess intake rates. However, Cantor et al. (1987) noted that retrospective dietary assessments generally produce moderate correlations with "reference data from the past." A summary of the recommended values for drinking water intake rates is presented in Table 3-30.

Adults - The total tapwater consumption rates for adults (older than 18 or 20 years) that have been reported in the key surveys can be summarized in Table 3-31. For comparison, values for daily tapwater intake for the relevant studies are shown in Table 3-32.

Note that both Ershow and Cantor (1989) and Pennington (1983) found that adults above 60 years of age had larger intakes than younger adults. This is difficult to reconcile with the Cantor et al. (1987) study because the latter, older population had a smaller average intake. Because of these results, combined with the fact that the Cantor et al. (1987) study was not intended to be representative of the U.S. population, it is not included here in the determination of the recommended value. The

Table 3-28. Planning Factors for Individual Tapwater 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 work force 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 3.29 Drinking Water Intake Surveys

Study	Number of Individuals	Type of Water Consumed	Time Period/ Survey Type	Population Surveyed	Comments
KEY					
Canadian Ministry of National Health and Welfare, 1981	970	Total tap water consumption	Weekday and weekend day in both summer and winter; estimation based on sizes and types of containers used	All ages, Canada	Seasonal data, includes many tapwater-containing items not commonly surveyed, possible bias because identification of vessel size used as survey techniques, short term study
Ershow and Cantor, 1989	Based on data from NHCS, approximately 30,000 individuals	Total tapwater, total fluid consumption	3-day recall, diaries	All ages, large sample representative of U.S. population	Short term recall data, seasonally balanced data
Rosenberry and Burmaster, 1992	Based on data from Ershow and Cantor, 1989	Total tapwater, total fluid consumption	3 day recall, diaries	All ages, large sample representative of U.S. population	Short term recall data; seasonally balanced, suitable for Monte Carlo simulations
RELEVANT					
Carter et al., 1987	5,258	Total tapwater, total fluid consumption	1 week/usual intake in winter based on recall	Adults only; weighted toward older adults; U.S. population	Based on recall of behavior from previous winter, short term data, population not representative of general U.S. population
Gillies and Paulin, 1983	160	Total tapwater consumption	24 hours, duplicate water samples collected	Adults only, New Zealand	Based on short term data
Hopkin and Ellis, 1980	3,564	Total tapwater, total liquid consumption	1 week period, diaries	All ages, Great Britain	Short term diary data
ICRP, 1981	Based on data from several sources	Water and water based drinks, milk; total fluids	NA[a]	NA[a]	Survey design and intake categories not clearly defined
NAS, 1977	Calculated average based on several sources	Average per capita "liquid" consumption	NA[a]	NA[a]	Total tapwater not reported, population and survey design not reported

Table 3-29 Drinking Water Intake Surveys (continued)

Study	Number of Individuals	Type of Water Consumed	Time Period/ Survey Type	Population Surveyed	Comments
Pennington, 1983	Based on NFCS and NHANES II, approximately 30,000 and 20,000 participants, respectively	Total tapwater, total fluid consumption	NFCS 24 hour recall on 2 day diary, NHANES II 24 hour recall	NFCS 1 month to 97 years NHANES II 6 months to 74 years, representative samples of U.S. population	Based on short term recall data
USDA, 1995	Based on 89-91 CSFII, approximately 15,000 individuals	Plain drinking water, coffee, tea, fruit drinks and ades	1 day recall	All ages, large sample representative of U.S. population	Short term recall data, seasonally adjusted
U.S. EPA, 1984	Based on NFCS, approximately 30,000 individuals	Tapwater, water based foods and beverages, soups, beverage consumption	3 day recall, diaries	All ages, large sample representative of U.S. population	Short term recall data, seasonally balanced
U.S. EPA, 1995	Over 4,000 participants of NHAPS	Number of glasses of drinking water and juice with tapwater	24 hour diaries	All ages, large representative sample of U.S. population	Does not provide data on the volume of tapwater consumed
McNall and Schlegel, 1968	Based on 2 groups of 8 subjects each	Tapwater	8 hour work cycle	Males between 17-25 years of age, small sample, high activity levels, hot climates	Based on short term data
U.S. Army, 1983	NA	All fluids consumed to satisfy body needs for internal water, includes soups, hot and cold drinks and tapwater	NA	High activity levels, hot climates	Study designed to provide water consumption planning factors for various activities and field conditions, based on estimated amount of water required to account for losses from urination, perspiration, and respiration

[a] Not applicable

Table 3-31. Summary of Recommended Drinking Water Intake Rates

Age Group/ Population	Mean	Percentiles 50th	90th	95th	Multiple	Fitted Distributions
<1 year[a]	0.30 L/day 44 mL/kg-day	0.24 L/day 35 mL/kg-day	0.65 L/day 102 mL/kg-day	0.76 L/day 127 mL/kg-day	Tables 3-6, 3-7, and 3-8	Table 3-11[b]
<5 years[a]	0.61 L/day	–	1.5 L/day	–	Table3-3	
3-5 years[a]	0.87 L/day	–	1.5 L/day	–	Table3-3	
1-10 years[a]	0.74 L/day 35 mL/kg-day	0.66 L/day 31 mL/kg-day	1.3 L/day 64 mL/kg-day	1.5 L/day 79.4 mL/kg-day	Tables 3-6, 3-7, and 3-8	Table 3-11[b]
11-19 years[a]	0.97 L/day 18 mL/kg-day	0.87 L/day 16 mL/kg-day	1.7 L/day 32 mL/kg-day	2.0 L/day 40 mL/kg-day	Tables 3-6, 3-7, and 3-8	Table 3-11[b]
Adults[a]	1.4 L/day 21 mL/kg-day	1.3 L/day 19 mL/kg-day	2.3 L/day 34 mL/kg-day		Tables 3-6, 3-7, and 3-8	Table 3-11[b]
Pregnant Women[d]	1.2 L/day 18.3 mL/kg-day	1.1 L/day 16 mL/kg-day	2.2 L/day 35 mL/kg-day	2.4 L/day 40 mL/kg-day	Table 3-25	
Lactating Women[d]	1.3 L/day 21.4 mL/kg-day	1.3 L/day 21 mL/kg-day	1.9 L/day 35 mL/kg-day	2.2 L/day 37 mL/kg-day	Table 3-25	
Adults in High Activity/Hot Climate Conditions[e]	0.21 to 0.65 L/hour, depending on ambient temperature and activity level; see Table 3-27.					
Active Adults[f]	6 L/day (temperate climate) to 11 L/day (hot climate); see Table 3-28.					

a. Source: Ershow and Cantor, 1989
b. Source: Roseberry and Burmaster, 1992
c. Source: Canadian Ministry of Health and Welfare, 1981
d. Ershow et al. (1991) presented data for pregnant women, lactating women, and control women.
e. Source: McNall and Schlegal, 1968
f. Source: U.S. Army, 1987

Table 3-31. Total Tapwater Consumption Rates From Key Studies

Mean (L/day)	90th Percentile (L/day)	Number in Survey	Reference
1.38	2.41	639	Canadian Ministry of Health and Welfare, 1981
1.41	2.28	11,731	Ershow and Cantor, 1989

Table 3-32. Daily Tapwater Intake Rates From Relevant Studies

Mean (L/day)	90th Percentile	Reference
1.30*	2.40	Cantor et al., 1987
1.53 (calculated)	–	NAS, 1977
1.25	1.90	Gilbes and Paulin, 1983
1.06 (25 to 30 yrs)	–	Pennington, 1983
1.26 (60 to 65 yrs)	–	Pennington, 1983
1.04-1.47 (ages 20+)	–	U.S. EPA, 1984
1.37 (20 to 64 yrs)	2.27	Ershow and Cantor, 1989
1.46 (65+ yrs)	2.29	Ershow and Cantor, 1989
1.15	–	USDA, 1995
1.07	1.87	Hopkins and Ellis, 1980

* Age of the Cantor et al. (1987) population was higher than the U.S. average.

USDA (1995) data are not included because tapwater was not defined in the survey and because the response rate was low, although the results (showing lower intakes than the studies based on older data) may be accurately reflecting an expected lower use of tapwater (compared to 1978) because of increasing use of bottled water and soft drinks in recent years.

A value of 1.41 L/day, which is the population-weighted mean of the two national studies (Ershow and Cantor, 1989 and Canadian Ministry of Health and Welfare, 1981) is the recommended average tapwater intake rate.

The average of the 90th percentile values from the same two studies (2.35 L/day) is recommended as the appropriate upper limit. (The commonly-used 2.0 L/day intake rate corresponds to the 84th percentile of the intake rate distribution among the adults in the Ershow and Cantor (1989) study). In keeping with the desire to incorporate body weight into exposure assessments without introducing extraneous errors, the values from the

Ershow and Cantor (1989) study (Tables 3-7 and 3-8) expressed as mL/kg-day are recommended in preference to the liters/day units. For adults, the mean and 90th percentile values are 21 mL/kg-day and 34.2 mL/kg/day, respectively.

In the absence of actual data on chronic intake, the values in the previous paragraph are recommended as chronic values, although the chronic 90th upper percentile may very well be larger than 2.35 L/day. If a mathematical description of the intake distribution is needed, the parameters of lognormal fit to the Ershow and Cantor (1989) data (Tables 3-11 and 3-12) generated by Roseberry and Burmaster (1992) may be used. The simulated balanced population distribution of intakes generated by Roseberry and Burmaster is not recommended for use in the post-1997 time frame, since it corrects the 1978 data only for the differences in the age structure of the U. S. population between 1978 and 1988.

These recommended values are different than the 2 liters/day commonly assumed in EPA risk assessments. Assessors are encouraged to use values which most accurately reflect the exposed population. When using values other than 2 liters/day, however, the assessors should consider if the dose estimate will be used to estimate risk by combining with a dose-response relationship which was derived assuming a tap water intake of 2 liters/day. If such an inconsistency exists, the assessor should adjust the dose-response relationship as described in Appendix 1 of Chapter 1. IRIS does not use a tap water intake assumption in the derivation of RfCs and RfDs, but does make the 2 liter/day assumption in the derivation of cancer slope factors and unit risks.

Children - The tapwater intake rates for children reported in the key studies are summarized in Table 3-33.

The intake rates, as expressed as liters per day, generally increase with age, and the data are consistent across ages for the two key studies except for the Canadian Ministry of Health and Welfare (1981) data for ages 6 to 17 years; it is recommended that any of the liters/day values that match the age range of interest except the Canada data for ages 6 to 17 years be used. The mL/kg-day intake values show a consistent downward trend with increasing ages; using the Ershow and Cantor (1989) data in preference to the Canadian Ministry of National Health and Welfare (1981) data is recommended where the age ranges overlap.

The intakes for children as reported in the relevant studies are shown in Table 3-34.

Table 3-33 Key Study Tapwater Intake Rates for Children

Age (years)	Mean (L/day)	90th Percentile (L/day)	Reference
<1	0.30	0.65	Ershow and Cantor, 1989
<3	0.61	1.50	Canadian Ministry of National Health and Welfare, 1981
3-5	0.87	1.50	Canadian Ministry of National Health and Welfare, 1981
1-10	0.74	1.29	Ershow and Cantor, 1989
6-17	1.14	2.21	Canadian Ministry of National Health and Welfare, 1981
11-19	0.97	1.70	Ershow and Cantor, 1989

Table 3-34 Summary of Intake Rates for Children in Relevant Studies

Age	Mean (L/day)	Reference
6-11 months	0.20	Pennington, 1983
<1 yr	0.19	U.S. EPA, 1984
<1 yr	0.32	Roseberry and Burmaster, 1992
2 yrs	0.50	Pennington, 1983
1-4 yrs	0.58	U.S. EPA, 1984
5-9 yrs	0.67	U.S. EPA, 1984
1-10 yrs	0.70	Roseberry and Burmaster, 1992
10-14 yrs	0.80	U.S. EPA, 1984
14-16 yrs	0.72	Pennington, 1983
15-19 yrs	0.90	U.S. EPA, 1984
11-19 yrs	0.91	Roseberry and Burmaster, 1992

Disregarding the Roseberry and Burmaster study, which is a recalculation of the Ershow and Cantor (1989) study, the non-key studies generally have lower mean intake values than the Ershow and Cantor (1899) study. The reason is not known, but the results are not persuasive enough to discount the recommendations based on the latter study. Intake rates for specific percentiles of the distribution may be selected using the lognormal distribution data generated by Roseberry and Burmaster (1992) (Tables 3-11 and 3-12).

Pregnant and Lactating Women -The data on tapwater intakes for control, pregnant, and lactating

women are presented in Table 3-25. The recommended intake values are presented in Table 3-30.

High Activity/Hot Climates - Data on intake rates for individuals performing strenuous activities under various environmental conditions are limited. None of these is classed as a key study because the populations in these studies are not representative of the general U.S. population. However, the data presented by McNall and Schlegel (1968) and U.S. Army (1983) provide bounding intake values for these individuals. According to McNall and Schlegel (1968), hourly intake can range from 0.21 to 0.65 L/hour depending on the temperature and activity level. Intake among physically active individuals can range from 6 L/day in temperate climates to 11 L/day in hot climates (U.S. Army, 1983).

A characterization of the overall confidence in the accuracy and appropriateness of the recommendations for drinking water is presented in Table 3-35. Although the study of Ershow and Cantor (1989) is of high quality and consistent with the other surveys, the low currency of the information (1978 data collection), in the presence of anecdotal information (not presented here) that the consumption of bottled water and beverages has increased since 1980 was the main reason for lowering the confidence score of the overall recommendations from high to medium.

3.7. REFERENCES FOR CHAPTER 3

American Industrial Health Council (AIHC). (1994) Exposure factors sourcebook. AIHC, Washington, DC.

Bourne, G.H.; Kidder, G.W., eds. (1953) Biochemistry and physiology of nutrition. Vol. 1. New York, NY: Academic Press.

Canadian Ministry of National Health and Welfare (1981) Tapwater consumption in Canada. Document number 82-EHD-80. Public Affairs Directorate, Department of National Health and Welfare, Ottawa, Canada.

Cantor, K.P.; Hoover, R.; Hartge, P.; Mason, T.J.; Silverman, D.T.; et al. (1987) Bladder cancer, drinking water source, and tapwater consumption: A case-control study. J. Natl. Cancer Inst. 79(6):1269-1279.

Ershow, A.G.; Brown, L.M.; Cantor, K.P. (1991) Intake of tapwater and total water by pregnant and lactating women. American Journal of Public Health. 81:328-334.

Ershow, A.G.; Cantor, K.P. (1989) Total water and tapwater intake in the United States: population-based estimates of quantities and sources. Life Sciences Research Office, Federation of American Societies for Experimental Biology.

Evans, C.L., ed. (1941) Starling's principles of human physiology, 8th ed. Philadelphia, PA: Lea and Febiger.

Gillies, M.E.; Paulin, H.V. (1983) Variability of mineral intakes from drinking water: A possible explanation for the controversy over the relationship of water quality to cardiovascular disease. Int. J. Epid. 12(1):45-50.

Guyton, A.C. (1968) Textbook of medical physiology, 3rd ed. Philadelphia, PA: W.B. Saunders Co.

Hopkins, S.M.; Ellis, J.C. (1980) Drinking water consumption in Great Britain: a survey of drinking habits with special reference to tap-water-based beverages. Technical Report 137, Water Research Centre, Wiltshire Great Britain.

ICRP. (1981) International Commission on Radiological Protection. Report of the task group on reference man. New York: Pergammon Press.

McNall, P.E.; Schlegel, J.C. (1968) Practical thermal environmental limits for young adult males working in hot, humid environments. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Transactions 74:225-235.

National Academy of Sciences (NAS). (1974) Recommended dietary allowances, 8th ed. Washington, DC: National Academy of Sciences-National Research Council.

National Academy of Sciences (NAS). (1977) Drinking water and health. Vol. 1. Washington, DC: National Academy of Sciences-National Research Council.

Pennington, J.A.T. (1983) Revision of the total diet study food list and diets. J. Am. Diet. Assoc. 82:166-173.

Pike, R.L.; Brown, M. (1975) Minerals and water in nutrition--an integrated approach, 2nd ed. New York, NY: John Wiley.

Randall, H.T. (1973) Water, electrolytes and acid base balance. In: Goodhart RS, Shils ME, eds. Modern nutrition in health and disease. Philadelphia, PA: Lea and Febiger.

Roseberry, A.M.; Burmaster, D.E. (1992) Lognormal distribution for water intake by children and adults. Risk Analysis 12:99-104.

Tsang, A.M.; Klepeis, N.E. (1996) Results tables from a detailed analysis of the National Human Activity Pattern Survey (NHAPS) responses. Draft Report prepared for the U.S. Environmental Protection Agency by Lockheed Martin, Contract No. 68-W6-001, Delivery Order No. 13.

U.S. Army. (1983) Water Consumption Planning Factors Study. Directorate of Combat Developments, United States Army Quartermaster School, Fort Lee, Virginia.

USDA. (1995) Food and nutrient intakes by individuals in the United States, 1 day, 1989-91. United States Department of Agriculture, Agricultural Research Service. NFS Report No. 91-2.

U.S. EPA. (1980) U.S. Environmental Protection Agency. Water quality criteria documents; availability. Federal Register, (November 28) 45(231):79318-79379.

U.S. EPA. (1984) An estimation of the daily average food intake by age and sex for use in assessing the radionuclide intake of individuals in the general population. EPA-520/1-84-021.

U.S. EPA. (1991) U.S. Environmental Protection Agency. National Primary Drinking Water Regulation; Final Rule. Federal Register 56(20):3526-3597. January 30, 1991.

Table 3-35 Confidence in Tapwater Intake Recommendations

Considerations	Rationale	Rating
Study Elements		
• Level of peer review	The study of Ershow and Cantor (1989) had a thorough expert panel review. Review procedures were not reported in the Canadian study; it was a government report. Other reports presented are published in scientific journals.	High
• Accessibility	The two monographs are available from the sponsoring agencies; the others are library-accessible.	High
• Reproducibility	Methods are well-described.	High
• Focus on factor of interest	The studies are directly relevant to tapwater.	High
• Data pertinent to U.S.	See "representativeness" below.	NA
• Primary data	The two monographs used recent primary data (less than one week) on recall of intake.	High
• Currency	Data were all collected in the 1978 era. Tapwater use may have changed since that time period.	Low
• Adequacy of data collection period	These are one- to three-day intake data. However, long term variability may be small. Their use as a chronic intake measure can be assumed.	Medium
• Validity of approach	The approach was competently executed.	High
• Study size	This study was the largest monograph that had data for 11,000 individuals.	High
• Representativeness of the population	The Ershow and Cantor (1989) and Canadian surveys were validated as demographically representative.	High
• Characterization of variability	The full distributions were given in the main studies.	High
• Lack of bias in study design (high rating is desirable)	Bias was not apparent.	High
• Measurement error	No physical measurements were taken. The method relied on recent recall of standardized volumes of drinking water containers, and was not validated.	Medium
Other Elements		
• Number of studies	There were two key studies for the adult and child recommendations. There were six other studies for adults, one study for pregnant and lactating women, and two studies for high activity/hot climates.	High for adult and children. Low for the other recommended subpopulation values.
• Agreement between researchers	This agreement was good.	High
Overall Rating	The data are excellent, but are not current	Medium

Walker, B.S.; Boyd, W.C.; Asimov, I. (1957) Biochemistry and human metabolism. 2nd ed. Baltimore, MD: Williams & Wilkins Co.

Wolf, A.V. (1958) Body water. Sci. Am. 99:125.

4. SOIL INGESTION AND PICA

4.1. BACKGROUND

The ingestion of soil is a potential source of human exposure to toxicants. The potential for exposure to contaminants via this source is greater for children because they are more likely to ingest more soil than adults as a result of behavioral patterns present during childhood. Inadvertent soil ingestion among children may occur through the mouthing of objects or hands. Mouthing behavior is considered to be a normal phase of childhood development. Adults may also ingest soil or dust particles that adhere to food, cigarettes, or their hands. Deliberate soil ingestion is defined as pica and is considered to be relatively uncommon. Because normal, inadvertent soil ingestion is more prevalent and data for individuals with pica behavior are limited, this section focuses primarily on normal soil ingestion that occurs as a result of mouthing or unintentional hand-to-mouth activity.

Several studies have been conducted to estimate the amount of soil ingested by children. Most of the early studies attempted to estimate the amount of soil ingested by measuring the amount of dirt present on children's hands and making generalizations based on behavior. More recently, soil intake studies have been conducted using a methodology that measures trace elements in feces and soil that are believed to be poorly absorbed in the gut. These measurements are used to estimate the amount of soil ingested over a specified time period. The available studies on soil intake are summarized in the following sections. Studies on soil intake among children have been classified as either key studies or relevant studies based on their applicability to exposure assessment needs. Recommended intake rates are based on the results of key studies, but relevant studies are also presented to provide the reader with added perspective on the current state-of-knowledge pertaining to soil intake. Information on soil ingestion among adults is presented based on available data from a limited number of studies. This is an area where more data and more research are needed. Relevant information on the prevalence of pica and intake among individuals exhibiting pica behavior is also presented.

4.2. KEY STUDIES ON SOIL INTAKE AMONG CHILDREN

Binder et al. (1986) - Estimating Soil Ingestion: Use of Tracer Elements in Estimating the Amount of Soil Ingested by Young Children - Binder et al. (1986) studied the ingestion of soil among children 1 to 3 years of age who wore diapers using a tracer technique modified from a method previously used to measure soil ingestion among grazing animals. 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. This made them useful tracers for estimating soil intake. Excreta measurements were obtained for 59 of the children. Soil ingestion by each child was estimated based on each of the three tracer elements using a standard assumed fecal dry weight of 15 g/day, and the following equation:

$$T_{i,e} = \frac{f_{i,e} \times F_i}{S_{i,e}} \qquad \text{(Eqn. 4-1)}$$

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 conducted by Binder et al. (1986) 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 housedust 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 (Table 4-1). The

Table 4-1. Estimated Daily Soil Ingestion Based on Aluminum, Silicon, and Titanium Concentrations

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	5,78	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.

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 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 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.

The advantages of this study are that a relatively large number of children were studied and tracer elements were used to estimate soil ingestion. However, the children studied may not be representative of the U.S. population and the study did not account for tracers ingested via foods or medicines. Also, the use of an assumed fecal weight instead of actual fecal weights may have biased the results of this study. Finally, because of the short-term nature of the survey, soil intake estimates may not be entirely representative of long-term behavior, especially at the upper-end of the distribution of intake.

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 similar to that of Binder et al. (1986). Aluminum, titanium, and acid-insoluble residue (AIR) contents were determined for fecal samples from children, aged 2 to 4 years, attending a nursery school, and for samples of playground dirt at that school. Twenty-seven daily fecal samples were obtained over a 5-day period for the 18 children examined. Using the average soil concentrations present at the school, and assuming a standard fecal dry weight of 10 g/day, Clausing et al. (1987) estimated soil ingestion for each tracer. Clausing et al. (1987) also collected eight daily fecal samples from six hospitalized, bedridden children. These children served as a control group, representing children who had very limited access to soil.

The average quantity of soil ingested by the school children in this study was as follows: 230 mg/day (range 23 to 979 mg/day) for aluminum; 129 mg/day (range 48 to 362 mg/day) for AIR; and 1,430 mg/day (range 64 to 11,620 mg/day) for titanium (Table 4-2). As in the Binder et al. (1986) study, a fraction of the children (6/19) showed titanium values well above 1,000 mg/day, with most of the remaining children showing substantially lower values. Based on the Limiting Tracer Method (LTM), mean soil intake was estimated to be 105 mg/day with a population standard deviation of 67 mg/day (range 23 to 362 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). Geometric mean soil intake was estimated to be 90 mg/day. This assumes that the maximum amount of soil ingested cannot be higher than the lowest estimate for the individual tracers.

Mean soil intake for the hospitalized children was estimated to be 56 mg/day based on aluminum (Table 4-3). For titanium, three of the children had estimates well in excess of 1,000 mg/day, with the remaining three children in the range of 28 to 58 mg/day. Using the LTM

Table 4-2. Calculated Soil Ingestion by 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 AlR (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

Source: Adapted from Clausing et al. 1987

Table 4-3. Calculated Soil Ingestion by 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	94
	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

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 intake rate was 45 mg/day. The data on hospitalized children suggest a major nonsoil source of titanium for some children, and may suggest a background nonsoil

source of aluminum. However, conditions specific to hospitalization (e.g., medications) were not considered. AIR measurements were not reported for the hospitalized children. Assuming that the tracer-based soil ingestion rates observed in hospitalized children actually represent background tracer intake from dietary and other nonsoil sources, mean soil ingestion by nursery school children was estimated to be 56 mg/day, based on the LTM (i.e., 105 mg/day for nursery school children minus 49 mg/day for hospitalized children) (Clausing et al. 1987).

The advantages of this study are that Clausing et al. (1987) evaluated soil ingestion among two populations of children that had differences in access to soil, and corrected soil intake rates based on background estimates derived from the hospitalized group. However, a smaller number of children were used in this study than in the Binder et al. (1986) study and these children may not be representative of the U.S. population. Tracer elements in foods or medicines were not evaluated. Also, intake rates derived from this study may not be representative of soil intake over the long-term because of the short-term nature of the study. In addition, one of the factors that could affect soil intake rates is hygiene (e.g., hand washing frequency). Hygienic practices can vary across countries and cultures and may be more stringently emphasized in a more structured environment such as child care centers in The Netherlands and other European countries than in child care centers in the United States.

Calabrese et al. (1989) - How Much Soil do Young Children Ingest: An Epidemiologic Study - Calabrese et al. (1989) studied soil ingestion among children using the basic tracer design developed by Binder et al. (1986). However, in contrast to the Binder et al. (1986) study, eight tracer elements (i.e., aluminum, barium, manganese, silicon, titanium, vanadium, yttrium, and zirconium) were analyzed instead of only three (i.e., aluminum, silicon, and titanium). A total of 64 children between the ages of 1 and 4 years old were included in the study. These children were all selected from the greater Amherst, Massachusetts area and were predominantly from two-parent households where the parents were highly educated. The Calabrese et al. (1989) study was conducted over eight days during a two week period and included the use of a mass-balance methodology in which duplicate samples of food, medicines, vitamins, and others were collected and analyzed on a daily basis, in addition to soil and dust samples collected from the child's home and play area. Fecal and urine samples were also collected and analyzed for tracer elements. Toothpaste, low in tracer content, was provided to all participants.

In order to validate the mass-balance methodology used to estimate soil ingestion rates among children and to determine which tracer elements provided the most reliable data on soil ingestion, known amounts of soil (i.e., 300 mg over three days and 1,500 mg over three days) containing eight tracers were administered to six adult volunteers (i.e., three males and three females). Soil samples and feces samples from these adults and duplicate food samples were analyzed for tracer elements to calculate recovery rates of tracer elements in soil. Based on the adult validation study, Calabrese et al. (1989) confirmed that the tracer methodology could adequately detect tracer elements in feces at levels expected to correspond with soil intake rates in children. Calabrese et al. (1989) also found that aluminum, silicon, and yttrium were the most reliable of the eight tracer elements analyzed. The standard deviation of recovery of these three tracers was the lowest and the percentage of recovery was closest to 100 percent (Calabrese, et al., 1989). The recovery of these three tracers ranged from 120 to 153 percent when 300 mg of soil had been ingested over a three-day period and from 88 to 94 percent when 1,500 mg soil had been ingested over a three-day period (Table 4-4).

Using the three most reliable tracer elements, the mean soil intake rate for children, adjusted to account for the amount of tracer found in food and medicines, was estimated to be 153 mg/day based on aluminum, 154 mg/day based on silicon, and 85 mg/day based on yttrium (Table 4-5). Median intake rates were somewhat lower (29 mg/day for aluminum, 40 mg/day for silicon, and 9 mg/day for yttrium). Upper-percentile (i.e., 95th) values were 223 mg/day for aluminum, 276 mg/day for silicon, and 106 mg/day for yttrium. Similar results were observed when soil and dust ingestion was combined (Table 4-5). Intake of soil and dust was estimated using a weighted average of tracer concentration in dust composite samples and in soil composite samples based on the timechildren spent at home and away from home, and indoors and outdoors. Calabrese et al. (1989) suggested that the use of titanium as a tracer in earlier studies that lacked food ingestion data may have significantly overestimated soil intake because of the high levels of titanium in food. Using the median values of aluminum and silicon, Calabrese et al. (1989) estimated the quantity of soil ingested daily to be 29 mg/day and 40 mg/day, respectively. It should be noted that soil

Table 4-4. Mean and Standard Deviation Percentage Recovery of Eight Tracer Elements

	300 mg Soil Ingested		1500 mg Soil Ingested	
Tracer Element	Mean	SD	Mean	SD
Al	152.8	107.5	93.5	15.5
Ba	2304.3	4533.0	149.8	69.5
Mn	1177.2	1341.0	248.3	183.6
Si	139.3	149.6	91.8	16.6
Ti	251.5	316.0	286.3	380.0
V	345.0	247.0	147.6	66.8
Y	120.5	42.4	87.5	12.6
Zr	80.6	43.7	54.6	33.4

Source: Adapted from Calabrese et al., 1989.

Table 4-5. Soil and Dust Ingestion Estimates for Children Aged 1-4 Years

Tracer Element	N	Intake (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
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
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
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

* Corrected for Tracer Concentrations in Foods

Source: Adapted from Calabrese et al., 1989

ingestion for one child in the study ranged from approximately 10 to 14 grams/day during the second week of observation. Average soil ingestion for this child was 5 to 7 mg/day, based on the entire study period.

The advantages of this study are that intake rates were corrected for tracer concentrations in foods and medicines and that the methodology was validated using adults. Also, intake was observed over a longer time period in this study than in earlier studies and the number of tracers used was larger than for other studies. A relatively large population was studied, but they may not be entirely representative of the U.S. population because they were selected from a single location.

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) also used a mass-balance/tracer 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. The study was conducted over a seven day period, primarily during the summer. Daily soil ingestion was evaluated by collecting and analyzing soil and house dust samples, feces, urine, and duplicate food samples for aluminum, silicon, and titanium. In addition, information on dietary habits and demographics was collected in an attempt to identify behavioral and demographic characteristics that influence soil intake rates among children. The amount of soil ingested on a daily basis was estimated using the following equation:

$$S_{i,e} = \frac{(DW_f - DW_p)}{} \qquad \text{(Eqn. 4-2)}$$

where:

$S_{i,e}$ = soil ingested for child i based on tracer e (g);
DW_f = feces dry weight (g);
DW_p = feces dry weight on toilet paper (g);
E_f = tracer amount in feces (μg/g);
E_u = tracer amount in urine (μg/g);
DW_{fd} = food dry weight (g);
E_{fd} = tracer amount in food (μg/g); and
E_{soil} = tracer concentration in soil (μg/g).

The soil intake rates were corrected by adding the amount of tracer in vitamins and medications to the amount of tracer in food, and adjusting the food quantities, feces dry weights, and tracer concentrations in urine to account for missing samples.

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 (Table 4-6). Median values were 25 mg/day for aluminum, 59 mg/day for silicon, and 81 mg/day for titanium. Davis et al. (1990) 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 mass balance 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. The adjusted mean soil/dust intake 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 intake rates were: 51.8 mg/day for aluminum, 112.4 mg/day for silicon, and 116.6 mg/day for titanium. Davis et al. (1990) also observed that the following demographic characteristics were associated with high soil intake rates: male sex, non-white racial group, low income, operator/laborer as the principal

Table 4-6. Average Daily Soil Ingestion Values Based on Aluminum, Silicon, and Titanium as Tracer Elements[a]

Element	Mean (mg/d)	Median (mg/d)	Standard Error of the Mean (mg/d)	Range (mg/d)[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 nonsoil sources of the tracer elements.
Source: Adapted from Davis et al., 1990.

occupation of the parent, and city of residence. However, none of these factors were predictive of soil intake rates when tested using multiple linear regression.

The advantages of the Davis et al. (1990) study are that soil intake rates were corrected based on the tracer content of foods and medicines and that a relatively large number of children were sampled. Also, demographic and behavioral information was collected for the survey group. However, although a relatively large sample population was surveyed, these children were all from a single area of the U.S. and may not be representative of the U.S. population as a whole. The study was conducted over a one-week period during the summer and may not be representative of long-term (i.e., annual) patterns of intake.

Van Wijnen et al. (1990) - Estimated Soil Ingestion by Children - In a study by Van Wijnen et al. (1990), soil ingestion among Dutch children ranging in age from 1 to 5 years was evaluated using a tracer element methodology similar to that used by Clausing et al. (1987). Van Wijnen et al. (1990) measured three tracers (i.e., titanium, aluminum, and AIR) in soil and feces and estimated soil ingestion based on the LTM. An average daily feces weight of 15 g dry weight was assumed. A total of 292 children attending daycare centers were sampled during the first of two sampling periods and 187 children were sampled in the second sampling period; 162 of these children were sampled during both periods (i.e., at the beginning and near the end of the summer of 1986). A total of 78 children were sampled at campgrounds, and 15 hospitalized children were sampled. The mean values for these groups were: 162 mg/day for children in daycare centers, 213 mg/day for campers and 93 mg/day for hospitalized children. Van Wijnen et al. (1990) also reported geometric mean LTM values because soil intake 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, 174 mg/day for children vacationing at campgrounds (Table 4-7) and 74 mg/day for hospitalized children (70-120 mg/day based on the 95 percent confidence limits of the mean). AIR was the limiting tracer in about 80 percent of the samples. Among children attending daycare centers, soil intake 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 (Table 4-8). Van Wijnen et al. (1990) suggest that the mean LTM value for hospitalized infants represents background intake of tracers and should be used to correct the soil intake rates based on LTM values for other sampling groups. Using mean values, corrected soil intake 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.

Table 4-7. Geometric Mean (GM) and Standard Deviation (GSD) LTM Values for Children at Daycare Centers and Campgrounds

Age (yrs)	Sex	Daycare Centers			Campgrounds		
		n	GM LTM (mg/day)	GSD LTM (mg/day)	n	GM LTM (mg/day)	GSD LTM (mg/day)
<1	Girls	3	81	1.09	-	-	-
	Boys	1	75	-	-	-	-
1-<2	Girls	20	124	1.87	3	207	1.99
	Boys	17	114	1.47	5	312	2.58
2-<3	Girls	34	118	1.74	4	367	2.44
	Boys	17	96	1.53	8	232	2.15
3-4	Girls	26	111	1.57	6	164	1.27
	Boys	29	110	1.32	8	148	1.42
4-<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 eight children.
[b] Age not registered for seven children.
Source: Adapted from Van Wijnen et al. 1990

Table 4-8. Estimated Geometric Mean LTM 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 precipitation)	1-<2	18	103	33	80
	2-<3	33	109	48	91
	4-<5	5	124	6	109
Reasonable	<1			1	61
(2-3 days/week precipitation)	1-<2			10	96
	2-<3			13	99
	3-<4			19	94
	4-<5			1	61
Good	<1	4	102		
(<2 days/week precipitation)	1-<2	42	229		
	2-<3	65	166		
	3-<4	67	138		
	4-<5	10	132		

Source: Van Wijnen et al. 1990)

Corrected geometric mean soil intake was estimated to range from 0 to 90 mg/day with a 90th percentile value of 190 mg/day for the various age categories within the daycare group and 30 to 200 mg/day with a 90th percentile value of 300 mg/day for the various age categories within the camping group.

The advantage of this study is that soil intake was estimated for three different populations of children: one expected to have high intake, one expected to have "typical" intake, and one expected to have low or background-level intake. Van Wijnen et al. (1990) used the background tracer measurements to correct soil intake rates for the other two populations. Tracer concentrations in food and medicine were not evaluated. Also, the population of children studied was relatively large, but may not be representative of the U.S. population. This study was conducted over a relatively short time period. Thus, estimated intake rates may not reflect long-term patterns, especially at the high-end of the distribution. Another limitation of this study is that values were not reported element-by-element which would be the preferred way of reporting. In addition, one of the factors that could affect soil intake rates is hygiene (e.g., hand washing frequency). Hygienic practices can vary across countries and cultures and may be more stringently emphasized in a more structured environment such as child care centers in The Netherlands and other European countries than in child care centers in the United States.

Stanek and Calabrese (1995a) - Daily Estimates of Soil Ingestion in Children - Stanek and Calabrese (1995a) presented a methodology which 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). In the Amherst study, soil ingestion measurements were made over a period of 2 weeks for a non-random sample of sixty-four children (ages of 1-4 years old) living adjacent to an academic area in western Massachusetts. During each week, duplicate food samples were collected for 3 consecutive days and fecal samples were collected for 4 consecutive days for each subject. The total amount of each of eight trace elements present in the food and fecal samples were measured. The eight trace elements are aluminum, barium, manganese, silicon, titanium, vanadium, yttrium, and zirconium. The authors expressed the amount of trace element in food input or

fecal output as a "soil equivalent," which was defined as the amount of the element in average daily food intake (or average daily fecal output) divided by the concentration of the element in soil. 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 (Stanek and Calabrese, 1995a). 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. Additionally, estimates of the distribution of soil ingestion projected over a period of 365 days were derived by fitting log-normal distributions to the "overall" daily soil ingestion estimates.

Table 4-9 presents the estimates of mean daily soil ingestion intake per child (mg/day) for the 64 study participants. (The authors also presented estimates of the median values of daily intake for each child. For most risk assessment purposes the child mean values, which are proportional to the cumulative soil intake by the child, are needed instead of the median values.) The approach adopted in this paper led to changes in ingestion estimates from those presented in Calabrese et al. (1989). Specifically, among elements that may be more useful for estimation of ingestion, the mean estimates decreased for Al (153 mg/d to 122 mg/d) and Si (154 mg/d to 139 mg/d), but increased for Ti (218 mg/d to 271 mg/d) and Y (85 mg/d to 165 mg/d). The "overall" mean estimate from this reanalysis was 179 mg/d. Table 4-9 presents the empirical distribution of the the "overall" mean daily soil ingestion estimates for the 8-day study period (not based on lognormal modeling). The estimated intake based on the "overall" estimates is 45 mg/day or less for 50 percent of the children and 208 mg/day or less for 95 percent of the children. The upper percentile values for most of the individual trace elements are somewhat higher. Next, estimates of the respondents soil intake averaged over a period of 365 days were presented based upon the lognormal models fit to the daily ingestion estimates (Table 4-10). The estimated median value of the 64 respondents' daily soil ingestion averaged over a year is 75 mg/day, while the 95th percentile is 1,751 mg/day.

A strength of this study is that it attempts to make full use of the collected data through estimation of daily ingestion rates for children. The data are then screened to remove less consistent tracer estimates and the remaining values are aggregated. Individual daily estimates of ingestion will be subject to larger errors than are weekly average values, particularly since the assumption of a constant lag time between food intake and fecal output may be not be correct for many subject days. The aggregation approach used to arrive at the "overall" ingestion estimates rests on the assumption that the mean

Table 4-9 Distribution of Average (Mean) Daily Soil Ingestion Estimates Per Child for 64 Children[a] (mg/day)

Type of Estimate Number of Samples	Overall (64)	Al (64)	Ba (33)	Mn (19)	Si (63)	Ti (56)	V (52)	Y (61)	Zr (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

ingestion estimates across acceptable tracers provides the most reliable ingestion estimates. The validity of this assumption depends on the particular set of tracers used in the study, and is not fully assessed.

Table 4-10. Estimated Distribution of Individual Mean Daily Soil Ingestion Based on Data for 64 Subjects Projected Over 365 Days[a]

Range	1 - 2,268 mg/d[b]
50th Percentile (median)	75 mg/d
90th Percentile	1,190 mg/d
95th Percentile	1,751 mg/d

[a] Based on fitting a log-normal distribution to model daily soil ingestion values.
[b] Subject with pica excluded.
Source: Stanek and Calabrese, 1995a

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) attempt to address this through lognormal modeling of the long term intake, new uncertainties are introduced through the parametric modeling of the limited subject day data. Also, the sample population size of the original study was small and site limited, and, therefore, is not representative of the U.S. population. Study mean estimates of soil ingestion, such as the study mean estimates presented in Table 4-9, are substantially more reliable than any available distributional estimates.

Stanek and Calabrese (1995b) - Soil Ingestion Estimates for Use in Site Evaluations Based on the Best Tracer Method - Stanek and Calabrese (1995b) recalculated ingestion rates that were estimated in three previous mass-balance studies (Calabrese et al., 1989 and Davis et al., 1990 for children's soil ingestion, and Calabrese et al., 1990 for adult soil ingestion) using the Best Tracer Method (BTM). This method allows for the selection of the most recoverable tracer for a particular subject or group of subjects. The selection process involves ordering trace elements for each subject based on food/soil (F/S) ratios. These ratios are estimated by dividing the total amount of the tracer in food by the tracer concentration in soil. The F/S ratio is small when the tracer concentration in food is almost zero when compared to the tracer concentration in soil. A small F/S ratio is desirable because it lessens 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. Because the recoverability of tracers can vary within any group of individuals, the BTM uses a ranking scheme of F/S ratios to determine the best tracers for use in the ingestion rate calculation. To reduce 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 among individuals.

For adults, Stanek and Calabrese (1995b) used data for 8 tracers from the Calabrese et al. (1990) 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 90th 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. (1990).

For children, Stanek and Calabrese (1995b) used data on 8 tracers from Calabrese et al., 1989 and data on 3 tracers from Davis et al. (1990) to estimate soil ingestion rates. The median of the soil ingestion estimates from the lowest four F/S ratios from the Calabrese et al. (1989) study most often included Al, Si, Ti, Y, and Zr. Based on the median of soil ingestion estimates from the best four tracers, the mean soil ingestion rate was 132 mg/day and the median was 33 mg/day. The 95th percentile value was 154 mg/day. These estimates are based on data for 128 subject weeks for the 64 children in the Calabrese et al. (1989) study. 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., Al, Si, and Ti) from the Davis et al. (1990) study. When the Calabrese et al. (1989) and Davis et al. (1990) studies were combined, soil ingestion was estimated to be 113 mg/day (mean); 37 mg/day (median); and 217 mg/day (95th percentile), using the BTM.

This study provides a reevaluation of previous studies. Its advantages are that it combines data from 2 studies for children, one from California and one from Massachusetts, which increases the number of

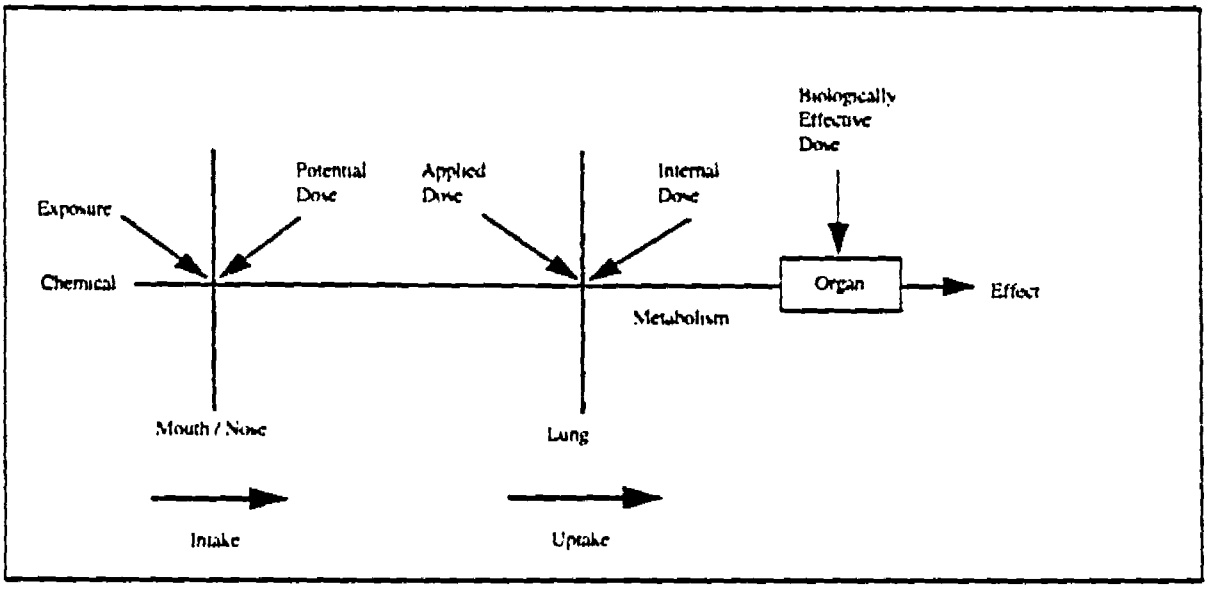


Figure 5-1. Schematic of Dose and Exposure: Respiratory Route

Source: U.S. EPA, 1992.

The respiratory system is comprised of three regions: nasopharyngeal, tracheobronchial, and pulmonary. The nasopharyngeal region extends from the nose to the larynx. The tracheobronchial region forms the conducting airways between nasopharynx and alveoli where gas exchange occurs. It consists of the trachea, bronchi, and bronchioles. The pulmonary regions consists of the acinus which is the site where gas exchange occurs; it is comprised of respiratory bronchioles, alveolar ducts and sacs, and alveoli. A detailed discussion of pulmonary anatomy and physiology can be found in: Benjamin (1988) and U.S. EPA (1989 and 1994).

Each region in the respiratory system can be involved with removing pollutants from inspired air. The nasopharyngeal region filters out large inhaled particles, moderates the temperature, and increases the humidity of the air. The surface of the tracheobronchial region is covered with ciliated mucous secreting cells which forms a mucociliary escalator that moves particles from deep regions of the lung to the oral cavity where they may be swallowed and then excreted. The branching pattern and physical dimensions of the these airways determine the pattern of deposition of airborne particles and absorption of gases by the respiratory tract. They decrease in diameter as they divide into a bifurcated branching network dilutes gases by axial diffusion of gases along the streamline of airways and radial diffusion of gases due to an increase in cross sectional area of the lungs. The velocity of the airstream in this decreasing branching network creates a turbulent force such that airborne particles can be deposited along the walls of these airways by impaction, interception, sedimentation, or diffusion depending on their size. The pulmonary region contains macrophages which engulf particles and pathogens that enter this portion of the lung.

Notwithstanding these removal mechanisms, both gaseous and particulate pollutants can deposit in various regions of the lung. Both the physiology of the lung and the chemistry of the pollutant influences where the pollutant tends to deposit.

Gaseous pollutants are evenly dispersed in the air stream. They come into contact with a large portion of the lung. Generally, their solubility and reactivity determines where they deposit in the lung. Water soluble and chemically reactive gases tend to deposit in the upper respiratory tract. Lipid soluble or non-reactive gases usually are not removed in the upper airways and tend to deposit in the distal portions of the lung. Gases can be

5. INHALATION ROUTE

This chapter presents data and recommendations for inhalation rates that can be used to assess exposure to contaminants in air. The studies discussed in this chapter have been classified as key or relevant. Key studies are used as the basis for deriving recommendations and the relevant studies are included to provide additional background and perspective. The recommended inhalation rates are summarized in Section 5.2.4 and cover adults, children, and outdoor workers/athletes.

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. In fact, it is unnecessary to calculate inhaled dose when using dose-response factors from Integrated Risk Information System (IRIS) (U.S. EPA, 1994). This is due to the fact that IRIS methodology accounts for inhalation rates in the development of "dose-response" relationships. 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 (RfC) 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 reference concentrations can be found in two methods manuals produced by the Agency (U.S. EPA, 1992; 1994).

IRIS employs a default inhalation rate of 20 m^3/day. This is greater than the recommendated value in this chapter. When using IRIS, adjustments of dose-response relationships using inhalation rates other than the default, 20 m^3/day, are not currently recommended. There are instances where the inhalation rate data presented in this chapter may be used for estimating average daily dose. For example, the inhalatino average daily dose is often estimated in cases where a compative pathway analysis is desired or to determine a total dose by adding across pathways in cases where RfCs and unit risk factors are not available.

5.1. EXPOSURE EQUATION FOR INHALATION

For those cases where the average daily dose (ADD) needs to be estimated, the general equation is:

$$ADD = [(C \times IR \times ED) / (BW \times AT)] \qquad \text{(Eqn. 5-1)}$$

where:

ADD	=	average daily dose (mg/kg-day);
C	=	*contaminant concentration in inhaled air* ($\mu g/m^3$);
IR	=	inhalation rate (m^3/day);
ED	=	exposure duration (days);
BW	=	body weight (kg); and
AT	=	averaging time (days), for non-carcinogenic effects AT = ED, for carcinogenic or chronic effects AT = 70 years or 25,550 days (lifetime).

The average daily dose is the dose rate averaged over a pathway-specific period of exposure expressed as a daily dose on a per-unit-body-weight basis. The ADD is used for exposure to chemicals with non-carcinogenic non-chronic effects. For compounds with carcinogenic or chronic effects, the lifetime average daily dose (LADD) is used. The LADD is the dose rate averaged over a lifetime. The contaminant concentration refers to the concentration of the contaminant in inhaled air. Exposure duration refers to the total time an individual is exposed to an air pollutant.

5.2. INHALATION RATE

5.2.1. Background

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 diminishes the pollutant concentration in inspired air (potential dose) such that the amount of a pollutant that actually enters the body through the lung (internal dose) is less than that measured at the boundary of the body (Figure 5-1). When constructing risk assessments that concern the inhalation route of exposure, one must be aware if any adjustments have been employed in the estimation of the pollutant concentration to account for this reduction in potential dose.

of soil ingested. Hum. Exp. Toxicol. 10:245-249.

Calabrese, E.J.; Stanek, E.J. (1992) Distinguishing outdoor soil ingestion from indoor dust ingestion in a soil pica child. Regul. Toxicol. Pharmacol. 15:83-85.

Calabrese, E.J.; Stanek, E.J. (1995) Resolving intertracer inconsistencies in soil ingestion estimation. Environ. Health Perspect. 103(5):454-456.

Clausing, P.; Brunekreef, B.; Van Wijnen, J.H. (1987) A method for estimating soil ingestion by children. Int. Arch. Occup. Environ. Health (W. Germany) 59(1):73-82.

Danford, D.C. (1982) Pica and nutrition. Annual Review of Nutrition. 2:303-322.

Davis, S.; Waller, P.; Buschbon, R.; Ballou, J.; White, P. (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. Arch. Environ. Hlth. 45:112-122.

Day, J.P.; Hart, M.; Robinson, M.S. (1975) Lead in urban street dust. Nature 253:343-345.

Duggan, M.J.; Williams, S. (1977) Lead in dust in city streets. Sci. Total Environ. 7:91-97.

Feldman, M.D. (1986) Pica: current perspectives. Psychosomatics (USA) 27(7):519-523.

Forfar, J.O.; Arneil, G.C., eds. (1984) Textbook of Paediatrics. 3rd ed. London: Churchill Livingstone.

Hawley, J.K. (1985) Assessment of health risk from exposure to contaminated soil. Risk Anal. 5:289-302.

Illingworth, R.S. (1983) The normal child. New York: Churchill Livingstone.

Kaplan, H.I.; Sadock, B.J. (1985) Comprehensive textbook of psychiatry/IV. Baltimore, MD: Williams and Wilkins.

Kimbrough, R.; Falk, H.; Stemr, P.; Fries, G. (1984) Health implications of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) contamination of residential soil. J. Toxicol. Environ. Health 14:47-93.

Krablin, R. (1989) [Letter to Jonathan Z. Cannon concerning soil ingestion rates.] Denver, CO: Arco Coal Co.; October 13, 1989.

Lepow, M.L.; Bruckman, L.; Robino, R.A.; Markowitz, S.; Gillette, M.; et al. (1974) Role of airborne lead in increased body burden of lead in Hartford children. Environ. Health Perspect. 6:99-101.

Lepow, M.L.; Buckman, L.; Gillette, M.; Markowitz, S.; Robino, R.; et al. (1975) Investigations into sources of lead in the environment of urban children. Environ. Res. 10:415-426.

Lourie, R.S.; Layman, E.M.; Millican, F.K. (1963) Why children eat things that are not food. Children 10:143-146.

Roels, H.; Buchet, J.P.; Lauwerys, R.R. (1980) Exposure to lead by the oral and pulmonary route of children living in the vicinity of a primary lead smelter. Environ. Res. 22:81-94.

Sayetta, R.B. (1986) Pica: An overview. American Family Physician 33(5):181-185.

Sedman, R.; Mahmood, R.S. (1994) Soil ingestion by children and adults reconsidered using the results of recent tracer studies. Air and Waste, 44:141-144.

Sheppard, S.C. (1995) Parameter values to model the soil ingestion pathway. Environmental Monitoring and Assessment 34:27-44.

Stanek, E.J.; Calabrese, E.J. (1995a) Daily estimates of soil ingestion in children. Environ. Health Perspect. 103(3):276-285.

Stanek, E.J.; Calabrese, E.J. (1995b) Soil ingestion estimates for use in site evaluations based on the best tracer method. Human and Ecological Risk Assessment. 1:133-156.

Thompson, K.M.; Burmaster, D.E. (1991) Parametric distributions for soil ingestion by children. Risk Analysis. 11:339-342.

U.S. EPA. (1984) Risk analysis of TCDD contaminated soil. Washington, DC: U.S. Environmental Protection Agency, Office of Health and Environmental Assessment. EPA 600/8-84-031.

Van Wijnen, J.H.; Clausing, P.; Brunekreff, B. (1990) Estimated soil ingestion by children. Environ. Res. 51:147-162.

Vermeer, D.E.; Frate, D.A. (1979) Geophagia in rural Mississippi: environmental and cultural contexts and nutritional implications. Am. J. Clin. Nutr. 32:2129-2135.

Table 4-22. Summary of Estimates of Soil Ingestion by Children

Mean (mg/day)					Upper Percentile (mg/day)				References
Al	Si	AIR[a]	Ti	Y	Al	Si	Ti	Y	
181	184				584	578			Binder et al. 1986
230		129							Clausing et al. 1987
39	82		245.5						Davis et al. 1990
64.5[b]	160[b]		268.4[b]						
153	154		218	85	223	276	1,432	106	Calabrese et al. 1989
154[b]	483[b]		170[b]	65[b]	478[b]	653[b]	1,059[b]	159[b]	
122	139	–	271	165	254	224	279	144	Stanek and Calabrese, 1995a
133[c]					217[c]				Stanek and Calabrese, 1995b
69-120[d]									Van Wijnen et al. 1990
Average =	146 mg/day soil 191 mg/day soil and dust combined				383 mg/day soil 587 mg/day soil and dust combined				

[a] AIR = Acid Insoluble Residue
[b] Soil and dust combined
[c] BTM
[d] LTM; composed value

Table 4-23. Summary of Recommended Values for Soil Ingestion

Population	Mean	Upper Percentile
Children	100 mg/day[a]	400 mg/day[b]
Adults	50 mg/day	--
Pica child	10 g/day[c]	---

[a] 200 mg/day may be used as a conservative estimate of the mean (see text).
[b] Study period was short; therefore, these values are not estimates of usual intake.
[c] To be used in acute exposure assessments. Based on only one pica child (Calabrese et al., 1989).

4.8. REFERENCES FOR CHAPTER 4

American Industrial Health Council (AIHC). (1994) Exposure factors sourcebook. AIHC, Washington, DC.

Binder, S.; Sokal, D.; Maughan, D. (1986) Estimating soil ingestion: the use of tracer elements in estimating the amount of soil ingested by young children. Arch. Environ. Health. 41(6):341-345.

Behrman, L.E.; Vaughan, V.C., III. (1983) Textbook of Pediatrics. Philadelphia, PA: W.B. Saunders Company.

Bruhn, C.M.; Pangborn, R.M. (1971) Reported incidence of pica among migrant families. J. of the Am. Diet. Assoc. 58:417-420.

Calabrese, E.J.; Kostecki, P.T.; Gilbert, C.E. (1987) How much soil do children eat? An emerging consideration for environmental health risk assessment. In press (Comments in Toxicology).

Calabrese, E.J.; Pastides, H.; Barnes, R.; Edwards, C.; Kostecki, P.T.; et al. (1989) How much soil do young children ingest: an epidemiologic study. In: Petroleum Contaminated Soils, Lewis Publishers, Chelsea, MI. pp. 363-397.

Calabrese, E.J.; Stanek, E.J.; Gilbert, C.E.; Barnes, R.M. (1990) Preliminary adult soil ingestion estimates; results of a pilot study. Regul. Toxicol. Pharmacol. 12:88-95.

Calabrese, E.J.; Stanek, E.J.; Gilbert, C.E. (1991) Evidence of soil-pica behavior and quantification

Table 4-21 Confidence in Soil Intake Recommendation

Considerations	Rationale	Rating
Study Elements		
• Level of peer review	All key studies are from peer review literature.	High
• Accessibility	Papers are widely available from peer review journals.	High
• Reproducibility	Methodology used was presented, but results are difficult to reproduce.	Medium
• Focus on factor of interest	The focus of the studies was on estimating soil intake rate by children; studies did not focus on intake rate by adults.	High (for children) Low (for adults)
• Data pertinent to U.S.	Two of the key studies focused on Dutch children, other studies used children from specific areas of the U.S.	Medium
• Primary data	All the studies were based on primary data.	High
• Currency	Studies were conducted after 1980	High
• Adequacy of data collection period	Children were not studied long enough to fully characterize day to day variability.	Medium
• Validity of approach	The basic approach is the only practical way to study soil intake, but refinements are needed in tracer selection and matching input with outputs. The more recent studies corrected the data for sources of the tracers in food. There are, however, some concerns about absorption of the tracers into the body and lag time between input and output.	Medium
• Study size	The sample sizes used in the key studies were adequate for children. However, only few adults have been studied	Medium (for children) Low (for adults)
• Representativeness of the population	The study population may not be representative of the U.S. in terms of race, socio-economics, and geographical location; Studies focused on specific areas; two of the studies used Dutch children.	Low
• Characterization of variability	Day-to-day variability was not very well characterized	Low
• Lack of bias in study design (high rating is desirable)	The selection of the population studied may introduce some bias in the results (i.e., children near a smelter site, volunteers in nursery school, Dutch children).	Medium
• Measurement error	Errors may result due to problems with absorption of the tracers in the body and mismatching inputs and outputs	Medium
Other Elements		
• Number of studies	There are 7 key studies	High
• Agreement between researchers	Despite the variability, there is general agreement among researchers on central estimates of daily intake for children	Medium
Overall Rating	Studies were well designed; results were fairly consistent, sample size was adequate for children and very small for adults; accuracy of methodology is uncertain; variability cannot be characterized due to limitations in data collection period. Insufficient data to recommend upper percentile estimates for both children and adults	Medium (for children - long-term central estimate) Low (for adults) Low (for upper percentile)

Table 4.20 Soil Intake Studies (continued)

Study	Study Type	Number of Observations	Population Studied: Age	Population Studied:	Comments
CHILDREN RELEVANT STUDIES (continued):					
Day et al., 1977	Measured dirt on sticky sweets and assumed number of sweets eaten per day	Not specified	Not specified	Not specified	Based on observations and crude measurements
Duggan and Williams, 1977	Measured soil on fingers and observed mouthing behavior	Not specified	Not specified	Areas around London	Based on observations and crude measurements
Hawley, 1985	Assumed soil intake rates based on nature and duration of activities	Not specified	Young children, older children, adults	Not specified	No data on soil intake collected, estimates based on assumptions regarding data from previous studies
Lepow et al., 1974, 1975	Measured soil on hands and observed mouthing behavior	32 children	2-6 years	Urban children from Connecticut	Based on observations over 3-6 hours of play and crude measurement techniques
Sedman and Mahmood, 1994	Adjusted data from earlier tracer-mass balance studies to generate mean soil intake rates for a 2 year old child	64 children from Calabrese et al., 1989 study and 104 children from Davis et al., 1990 study	Adjusted to 2 year old child	Same children as in Calabrese et al., 1989 and Davis et al., 1990 study	Based on data from Calabrese et al., 1989 and Davis et al., 1990
Sheppard, 1995	Provides estimates based on the current literature on soil ingestion from tracer methods and recommends values for use in assessments	Not specified	1 year adults (age not specified)	Various	Presents mean estimates for children and adults; provides ingestion estimates for indoor and outdoor activities based on Hawley, 1985.
Thompson and Burmaster, 1991	Re-evaluation of Binder et al., 1986 data	59 children	1-3 years	Children living near lead smelter in Montana	Re-calculated soil intake rates from Binder et al., 1986 data using actual fecal weights instead of assumed weights
ADULT SOIL INTAKE STUDIES:					
Hawley, 1985	Assumed soil intake rates based on nature and duration of activities	Not specified	Young children, older children, adults	Not specified	No data on soil intake collected, estimates based on assumptions regarding data from previous studies
Calabrese et al., 1990	Measured excretory output after ingestion of capsules with sterilized soil	6 adults	21-41 years	Healthy adult volunteers	Data used to validate the analytical methodology used in the children's study (Calabrese, 1989).
PICA STUDIES:					
Calabrese et al., 1991	Tracer - mass balance	1 pica child	3-5 years	1 pica child from greater Amherst area of Massachusetts	Child was observed as part of the Calabrese et al., 1989 study.
Calabrese and Stanek, 1992	Reanalysis of data from Calabrese et al., 1991	1 pica child	3-5 years	1 pica child from greater Amherst area of Massachusetts	Distinguished between outdoor soil ingestion and indoor dust ingestion in a soil pica child

Table 4.20 Soil Intake Studies

Study	Study Type	Number of Observations	Population Studied: Age	Population Studied:	Comments
CHILDREN KEY STUDIES:					
Binder et al., 1986	Tracer study using aluminum, silicon, and titanium	59 children	1-3 years	Children living near lead smelter in Montana	Did not account for tracers in food and medicine, used assumed fecal weight of 15 g/day, short term study conducted over 3 days
Calabrese et al., 1989	Tracer - mass balance study using aluminum, barium, manganese, silicon, titanium, vanadium, yttrium, and zirconium	64 Children	1-4 years	Children from greater Amherst area of Massachusetts, highly-educated parents	Corrected for tracer in food and medicine, study conducted over two week period, used adults to validate methods, one pica child in study group
Clausing et al., 1987	Tracer study using aluminum, acid insoluble residue, and titanium	18 nursery school children, 6 hospitalized children	2-4 years	Dutch children	Did not account for tracers in food and medicines, used tracer based intake rates for hospitalized children as background values, short term study conducted over 5 days
Davis et al., 1990	Tracer - mass balance study using aluminum silicon and titanium	104 children	2-7 years	Children from 3 city area in Washington State	Corrected for tracer in food and medicine, short term study conducted over seven day period, collected information on demographic characteristics affecting soil intake
Stanek and Calabrese, 1995a	Adjusted soil intake estimates	64 children	1-4 years	Same children as in Calabrese et al., 1989	Based on data from Calabrese et al., 1989
Stanek and Calabrese, 1995b	Recalculated intake rates based on three previous mass balance studies using the Best Tracer Method	164 children 6 adults	1-7 years 25-41 years	Children from three mass balance studies	Based on studies of Calabrese et al., 1989, Davis et al., 1990, and Calabrese et al., 1990
Van Wijnen et al., 1990	Tracer study using aluminum, acid insoluble residue, and titanium	292 day care children, 78 caregivers, 15 hospitalized children	1-5 years	Dutch children	Did not account for tracer in food and medicines, used tracer based intake for hospitalized children as background values, evaluated population (caregiver) with greater access to soil, evaluated differences in soil intake due to weather conditions
CHILDREN RELEVANT STUDIES					
ATSDR, 1994	Reanalysis of data from Calabrese et al., 1990	6 adults	21-41 years	Health adults	Used data from Calabrese et al (1990) study to derive soil ingestion rates using zirconium as a tracer, recent studies indicate that zirconium is not a good tracer
Calabrese and Stanek, 1995	Evaluated errors in soil ingestion estimates	64 children	1-4 years	Study population of Calabrese et al., 1989	Based on Calabrese et al., 1989 data

engaged in outdoor activities and a range of 0.56 to 110 mg/day of house dust during indoor activities. These estimates were derived from assumptions about soil/dust levels on hands and mouthing behavior; no supporting measurements were made. Making further assumptions about frequencies of indoor and outdoor activities, Hawley (1985) derived an annual average of 60.5 mg/day. Given the lack of supporting measurements, these estimates must be considered conjectural. Krablin (1989) used arsenic levels in urine (n=26) combined with information on mouthing behavior and activity patterns to suggest an estimate for adult soil ingestion of 10 mg/day. The study protocols are not well described and has not been formally published. Finally, Calabrese et al. (1990) conducted a tracer study on 6 adults and found a range of 30 to 100 mg/day. This study is probably the most reliable of the three, but still has two significant uncertainties: (1) representativeness of the general population is unknown due to the small study size (n=6); and (2) representativeness of long-term behavior is unknown since the study was conducted over only 2 weeks. In the past, many EPA risk assessments have assumed an adult soil ingestion rate of 50 mg/day for industrial settings and 100 mg/day for residential and agricultural scenarios. These values are within the range of estimates from the studies discussed above. Thus, 50 mg/day still represents a reasonable central estimate of adult soil ingestion and is the recommended value in this handbook. This recommendation is clearly highly uncertain; however, and as indicated in Table 4-21, is given a low confidence rating. Considering the uncertainties in the central estimate, a recommendation for an upper percentile value would be inappropriate. Table 4-23 summarizes soil ingestion recommendations for adults.

In conducting a risk assessment for TCDD, U.S. EPA (1984) used 5 g/day to represent the soil intake rate for pica children. The Centers for Disease Control (CDC) also investigated the potential for exposure to TCDD through the soil ingestion route. CDC used a value of 10 g/day to represent the amount of soil that a child with deliberate soil ingestion behavior might ingest (Kimbrough et al., 1984). These values are consistent with those observed by Calabrese et al. (1991).

4.7. RECOMMENDATIONS

The key studies described in this section were used to recommend values for soil intake among children. The key and relevant studies used different survey designs and study populations. These studies are summarized in Table 4-20. For example, some of the studies considered food and nonfood sources of trace elements, while others did not. In other studies, soil ingestion estimates were adjusted to account for the contribution of house dust to this estimate. Despite these differences, the mean and upper-percentile estimates reported for these studies are relatively consistent. The confidence rating for soil intake recommendations is presented in Table 4-21.

It is important, however, to understand the various uncertainties associated with these values. First, individuals were not studied for sufficient periods of time to get a good estimate of the usual intake. Therefore, the values presented in this section may not be representative of long term exposures. Second, the experimental error in measuring soil ingestion values for individual children is also a source of uncertainty. For example, incomplete sample collection of both input (i.e., food and nonfood sources) and output (i.e., urine and feces) is a limitation for some of the studies conducted. In addition, an individual's soil ingestion value may be artificially high or low depending on the extent to which a mismatch between input and output occurs due to individual variation in the gastrointestinal transit time. Third, the degree to which the tracer elements used in these studies are absorbed in the human body is uncertain. Accuracy of the soil ingestion estimates depends on how good this assumption is. Fourth, there is uncertainty with regard to the homogeneity of soil samples and the accuracy of parent's knowledge about their child's playing areas. Fifth, all the soil ingestion studies presented in this section with the exception of Calabrese et al. (1989) were conducted during the summer when soil contact is more likely.

Although the recommendations presented below are derived from studies which were mostly conducted in the summer, exposure during the winter months when the ground is frozen or snow covered should not be considered as zero. Exposure during these months, although lower than in the summer months, would not be zero because some portion of the house dust comes from outdoor soil.

Soil Ingestion Among Children - Estimates of the amount of soil ingested by children are summarized in Table 4-22. The mean values ranged from 39 mg/day to 271 mg/day with an average of 146 mg/day for soil ingestion and 191 mg/day for soil and dust ingestion. Results obtained using titanium as a tracer in the Binder et al. (1986) and Clausing et al. (1987) studies were not considered in the derivation of this recommendation because these studies did not take into consideration other sources of the element in the diet which for titanium seems to be significant. Therefore, these values may overestimate the soil intake. One can note that this group of mean values is consistent with the 200 mg/day value that EPA programs have used as a conservative mean estimate. Taking into consideration that the highest values were seen with titanium, which may exhibit greater variability than the other tracers, and the fact that the Calabrese et al. (1989) study included a pica child, 100 mg/day is the best estimate of the mean for children under 6 years of age. However, since the children were studied for short periods of time and the prevalence of pica behavior is not known, excluding the pica child from the calculations may underestimate soil intake rates. It is plausible that many children may exhibit some pica behavior if studied for longer periods of time. Over the period of study, upper percentile values ranged from 106 mg/day to 1,432 mg/day with an average of 383 mg/day for soil ingestion and 587 mg/day for soil and dust ingestion. Rounding to one significant figure, the recommended upper percentile soil ingestion rate for children is 400 mg/day. However, since the period of study was short, these values are not estimates of usual intake. The recommended values for soil ingestion among children and adults are summarized in Table 4-23.

Data on soil ingestion rates for children who deliberately ingest soil are also limited. An ingestion rate of 10 g/day is a reasonable value for use in acute exposure assessments, based on the available information. It should be noted, however, that this value is based on only one pica child observed in the Calabrese et al. (1989) study.

Soil Ingestion Among Adults - Only three studies have attempted to estimate adult soil ingestion. Hawley (1985) suggested a value of 480 mg/day for adults

during the first week of observation and 10.1 to 13.6 g/day during the second week of observation (Table 4-18). These results are based on mass-balance analyses for seven (i.e., aluminum, barium, manganese, silicon, titanium, vanadium, and yttrium) of the eight tracer elements used. Intake rates based on zirconium was significantly lower but Calabrese et al. (1991) indicated that this may have "resulted from a limitation in the analytical protocol."

Table 4-18. Daily Soil Ingestion Estimation in a Soil-Pica Child by Tracer and by Week (mg/day)

Tracer	Week 1 Estimated Soil Ingestion	Week 2 Estimated Soil Ingestion
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	13,125
Zr	86	7,605

Source: Calabrese et al. 1991

Calabrese and Stanek (1992) - Distinguishing Outdoor Soil Ingestion from Indoor Dust Ingestion in a Soil Pica Child - Calabrese and Stanek (1992) quantitatively distinguished the amount of outdoor soil ingestion from indoor dust ingestion in a soil pica child. This study was based on a previous mass-balance study (conducted in 1991) in which a 3-1/2 year old child ingested 10-13 grams of soil per day over the second week of a 2-week soil ingestion study. Also, the previous study utilized a soil tracer methodology with eight different tracers (Al, Ba, Mn, Si, Ti, V, Y, Zr). The reader is referred to Calabrese et al. (1989) for a detailed description and results of the soil ingestion study. Calabrese and Stanek (1992) distinguished indoor dust from outdoor soil in ingested soil based on a methodology which compared differential element ratios.

Table 4-19 presents tracer ratios of soil, dust, and residual fecal samples in the soil pica child. Calabrese and Stanek (1992) reported that there was a maximum total of 28 pairs of tracer ratios based on eight tracers. However, only 19 pairs of tracer ratios were available for quantitative evaluation as shown in Table 4-19. Of these 19 pairs, 9 fecal tracer ratios fell within the boundaries for soil and dust (Table 4-19). For these 9 tracer soils, an interpolation was performed to estimate the relative contribution of soil and dust to the residual fecal tracer ratio. The other 10 fecal tracer ratios that fell outside the soil and dust boundaries were concluded to be 100 percent of the fecal tracer ratios from soil origin (Calabrese and Stanek, 1992). Also, the 9 residual fecal samples within the boundaries revealed that a high percentage (71-99 percent) of the residual fecal tracers were estimated to be of soil origin. Therefore, Calabrese and Stanek (1992) concluded that the predominant proportion of the fecal tracers was from outdoor soil and not from indoor dust origin.

Table 4-19. Ratios of Soil, Dust, and Residual Fecal Samples in the Soil Pica Child

Tracer Ratio Pairs		Soil	Fecal	Dust	Estimated % of Residual Fecal Tracers of Soil Origin as Predicted by Specific Tracer Ratios
1.	Mn/Ti	208.368	215.241	260.126	87
2.	Ba/Ti	187.448	206.191	115.837	100
3.	Si/Ti	148.117	136.062	7.490	92
4.	V/Ti	14.603	10.261	17.887	100
5.	Al/Ti	18.410	21.087	13.326	100
6.	Y/Ti	8.577	9.621	5.669	100
7.	Mn/Y	24.293	22.373	45.882	100
8.	Ba/Y	21.854	21.432	20.432	71
9.	Si/Y	17.268	14.205	1.321	81
10.	V/Y	1.702	1.067	3.155	100
11.	Al/Y	2.146	2.192	2.351	88
12.	Mn/Al	11.318	10.207	19.520	100
13	Ba/Al	10.182	9.778	8.692	73
14.	Si/Al	8.045	6.481	0.562	81
15.	V/Al	0.793	0.487	1.342	100
16.	Si/V	10.143	13.318	0.419	100
17.	Mn/Si	1.407	1.575	34.732	99
18.	Ba/Si	1.266	1.509	15.466	83
19	Mn/Ba	1.112	1.044	2.246	100

Source: Calabrese and Stanek, 1992

Table 4-17. Adult Daily Soil Ingestion Estimates by Week and Tracer Element After Subtracting Food and Capsule Ingestion, Based on Median Amherst Soil Concentrations: Means and Medians Over Subjects (mg)[a]

Week	Al	Ba	Mn	Si	Ti	V	Y	Zr
Means								
1	110	-232	330	30	71	1,288	63	134
2	98	12,265	1,306	14	25	43	21	58
3	28	201	790	-23	896	532	67	-74
Medians								
1	60	-71	388	31	102	1,192	44	124
2	85	597	1,368	15	112	150	35	65
3	66	386	831	-27	156	647	60	-144

[a] Data were converted to milligrams
[b] Negative values occur because of correction for food and capsule ingestion.
Source: Calabrese et al., 1990

and 3 years (Sayetta, 1986). The incidence of deliberate ingestion behavior in children has been shown to differ for different subpopulations. The incidence rate appears to be higher for black children than for white children. Approximately 30 percent of black children aged 1 to 6 years are reported to have deliberate ingestion behavior, compared with 10 to 18 percent of white children in the same age group (Danford, 1982). There does not appear to be any sex differences in the incidence rates for males or females (Kaplan and Sadock, 1985). Lourie et al. (1963) states that the incidence of pica is higher among children in lower socioeconomic groups (i.e., 50 to 60 percent) than in higher income families (i.e., about 30 percent). Deliberate soil ingestion behavior appears to be more common in rural areas (Vermeer and Frate, 1979). A higher rate of pica has also been reported for pregnant women and individuals with poor nutritional status (Danford, 1982). In general, deliberate ingestion behavior is more frequent and more severe in mentally retarded children than in children in the general population (Behrman and Vaughan 1983, Danford 1982, Forfar and Arneil 1984, Illingworth 1983, Sayetta 1986).

It should be noted that the pica statistics cited above apply to the incidence of general pica and not soil pica. Information on the incidence of soil pica is limited, but it appears that soil pica is less common. A study by Vermeer and Frate (1979) showed that the incidence of geophagia (i.e., earth-eating) was about 16 percent among children from a rural black community in Mississippi. However, geophagia was described as a cultural practice among the community surveyed and may not be representative of the general population. Average daily consumption of soil was estimated to be 50 g/day. Bruhn and Pangborn (1971) reported the incidence of pica for "dirt" to be 19 percent in children, 14 percent in pregnant women, and 3 percent in nonpregnant women. However, "dirt" was not clearly defined. The Bruhn and Pangborn (1971) study was conducted among 91 non-black, low income families of migrant agricultural workers in California. Based on the data from the five key tracer studies (Binder et al., 1986; Clausing et al., 1987; Van Wijnen et al., 1990; Davis et al., 1990; and Calabrese et al., 1989) only one child out of the more than 600 children involved in all of these studies ingested an amount of soil significantly greater than the range for other children. Although these studies did not include data for all populations and were representative of short-term ingestions only, it can be assumed that the incidence rate of deliberate soil ingestion behavior in the general population is low. However, it is incumbent upon the user to use the appropriate value for their specific study population.

4.6. DELIBERATE SOIL INGESTION AMONG CHILDREN

Information on the amount of soil ingested by children with abnormal soil ingestion behavior is limited. However, some evidence suggests that a rate on the order of 10 g/day may not be unreasonable.

Calabrese et al. (1991) - Evidence of Soil Pica Behavior and Quantification of Soil Ingestion - Calabrese et al. (1991) estimated that upper range soil ingestion values may range from approximately 5-7 grams/day. This estimate was based on observations of one pica child among the 64 children who participated in the study. In the study, a 3.5-year old female exhibited extremely high soil ingestion behavior during one of the two weeks of observation. Intake ranged from 74 mg/day to 2.2 g/day

was assumed to occur 12 days/year. Hawley (1985) also assumed that soil comprises 80 percent of household dust. Based on these assumptions about soil intake and the frequency of indoor and outdoor activities, Hawley (1985) estimated the annual average soil intake rate for adults to be 60.5 mg/day (Table 4-16).

Table 4-16. Estimates of Soil Ingestion for Adults

Scenarios	Media	Exposure (mg/day)	Days/Year Activity	Fraction Soil Content	Annual Average Soil Intake (mg/day)
Adult					
Work in attic (year-round)	Dust	110	12	0.8	3
Living Space (year-round)	Dust	0.56	365	0.8	0.5
Outdoor Work (summer)	Soil	480	43	1	57
TOTAL SOIL INTAKE					60.5

Source: Hawley, 1985.

The soil intake value estimated by Hawley (1985) is consistent with adult soil intake rates suggested by other researchers. Calabrese et al. (1987) suggested that soil intake among adults ranges from 1 to 100 mg/day. According to Calabrese et al. (1987), these values "are conjectural and based on fractional estimates" of earlier Center for Disease Control (CDC) estimates. In an evaluation of the scientific literature concerning soil ingestion rates for children and adults (Krablin, 1989), Arco Coal Company suggested that 10 mg/day may be an appropriate value for adult soil ingestion. This value is based on "extrapolation from urine arsenic epidemiological studies and information on mouthing behavior and time activity patterns" (Krablin, 1989).

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 conducted by Calabrese and was used to validate part of the analytical methodology used in the children 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 mg of sterilized soil within a gelatin capsule at breakfast and at dinner (a total of 100 mg of sterilized soil per day) for 3 days. For the third week, the participants ingested 250 mg of sterilized soil in a gelatin capsule at breakfast and at dinner (a total of 500 mg of soil per day) during the three 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 were collected from Monday noon through Friday midnight over 3 consecutive weeks. Table 4-17 provides the mean and median values of soil ingestion for each element by week. Data obtained from the first week, when empty gelatin capsules were ingested, may be used to derive an estimate of soil intake by adults. The mean intake rates for the eight tracers are: Al, 110 mg; Ba, -232 mg; Mn, 330 mg; Si, 30 mg; Ti, 71 mg; V, 1,288 mg; Y, 63 mg; and Zr, 134 mg.

The advantage of this study is that it provides quantitative estimates of soil ingestion for adults. The study also corrected for tracer concentrations in foods and medicines. However, a limitation of this study is that a limited number of subjects were studied. In addition, the subjects were only studied for one week before soil capsules were ingested.

4.5. PREVALENCE OF PICA

The scientific literature define pica as "the repeated eating of non-nutritive substances" (Feldman, 1986). For the purposes of this handbook, pica is defined as an deliberately high soil ingestion rate. Numerous articles have been published that report on the incidence of pica among various populations. However, most of these papers describe pica for substances other than soil including sand, clay, paint, plaster, hair, string, cloth, glass, matches, paper, feces, and various other items. These papers indicate that the pica occurs in approximately half of all children between the ages of 1

accurate estimate of soil ingestion, and the validity of this assumption depends on the specific set of tracers used in the study and need not be correct. The approach used for the estimation of daily tracer intake is the same as in Stanek and Calabrese (1995a), and some limitations of that approach are mentioned in the review of that study.

Sheppard (1995) - Parameter Values to Model the Soil Ingestion Pathway - Sheppard (1995) summarized the available literature on soil ingestion to estimate the amount of soil ingestion in humans for the purposes of risk assessment. Sheppard (1995) categorized the available soil ingestion studies into two general approaches: (1) those that measured the soil intake rate with the use of tracers in the soil, and (2) those that estimated soil ingestion based on activity (e.g., hand-to-mouth) and exposure duration. Sheppard (1995) provided estimates of soil intake based on previously published tracer studies. The data from these studies were assumed to be lognormally distributed due to the broad range, the concept that soil ingestion is never zero, and the possibility of very high values. In order to account for skewness in the data, geometric means rather than arithmetic means, were calculated by age, excluding pica and geophagy values. The geometric mean for soil ingestion rate for children under six was estimated to be 100 mg/day. For children over six and adults, the geometric mean intake rate was estimated to be 20 mg/day. Sheppard (1995) also provided soil ingestion estimates for indoor and outdoor activities based on data from Hawley (1985) and assumptions regarding duration of exposure (Table 4-15).

Sheppard's (1995) estimates, based on activity and exposure duration, are quite similar to the mean values from intake rate estimates described in previous sections. The advantages of this study are that the model can be used to calculate the ingestion rate from non-food sources with variability in exposure ingestion rates and exposure durations. The limitation of this study is that it does not introduce new data; previous data are re-evaluated. In addition, because the model is based on previous data, the same advantages and limitations of those studies apply.

4.4. SOIL INTAKE AMONG ADULTS

Hawley 1985 - Assessment of Health Risk from Exposure to Contaminated Soil - Information on soil ingestion among adults is very limited. Hawley (1985) estimated soil ingestion among adults based on assumptions regarding activity patterns and corresponding ingestion amounts. Hawley (1985) assumed that adults ingest outdoor soil at a rate of 480 mg/day while engaged in yardwork or other physical activity. These outdoor exposures were assumed to occur 2 days/week during 5 months of the year (i.e., May through October). The ingestion estimate was based on the assumption that a 50 μm/thick layer of soil is ingested from the inside surfaces of the thumb and fingers of one hand. Ingestion of indoor housedust was assumed to occur from typical living space activities such as eating and smoking, and work in attics or other uncleaned areas of the house. Hawley (1985) assumed that adults ingest an average of 0.56 mg housedust/day during typical living space activities and 110 mg housedust/day while working in attics. Attic work

Table 4-15 Soil Ingestion Rates for Assessment Purposes

Receptor Age	Setting	Soil Load on Hands (mg/cm²)	Soil Exposure Ingestion Rate (mg/hr)	Suggested Exposure Durations (hr/yr)	Average Daily Soil Ingestion (mg/day)
Pica Child		---	1,000	200	500
2.5 yrs	Outdoor	0.5	20	1,000	50
	Indoor	0.4	3	Remaining[a]	60
6 yrs	Outdoor	0.5	10	700	20
	Indoor	0.08	0.15	5,000	2
Adult	Gardening	1.0	20	300	20
	Indoor	0.04	0.03	5,000	0.4

[a] Hawley (1985) assumed the child spent all the time at home, so that the indoor time was 8,760 hours/year minus the outdoor time
Source: Sheppard 1995

Possible sources of negative bias identified by Calabrese and Stanek (1995) are the following:

- Ingestion of tracers in food, but the tracers 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 which result in diminished detection of fecal tracers, but not in soil tracer levels.

The authors developed an approach which 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) daily soil ingestion rate was estimated for each tracer for each 24-hr day a fecal sample was obtained; (3) the median tracer-based soil ingestion rate for each subject-day was determined. Also, upper and lower bound estimates were determined based on criteria formed using an assumption of the magnitude of the relative standard deviation (RSD) 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; (4) negative errors due to missing fecal samples at the end of the study period were also determined (Calabrese and Stanek, 1995).

Table 4-14 presents the estimated magnitude of positive and negative error for six tracer elements in the children's study (i.e., conducted by Calabrese et al., 1989). The original mean soil ingestion rates ranged from a low of 21 mg/day based on zirconium to a high of 459 mg/day based on titanium (Table 4-14). 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 (Table 4-14). Calabrese and Stanek (1995) concluded that correcting for errors at the individual level for each tracer element provides more reliable estimates of soil ingestion.

This report is valuable in providing additional understanding of the nature of potential errors in trace element specific estimates of soil ingestion. However, the operational definition used for estimating the error in a trace element estimate was the observed difference of that tracer from a median tracer value. Specific identification of sources of error, or direct evidence that individual tracers were indeed in error was not developed. Corrections to individual tracer means were then made according to how different values for that tracer were from the median values. This approach is based on the hypothesis that the median tracer value is the most

Table 4-14. Positive/Negative Error (bias) in Soil Ingestion Estimates in the Calabrese et al. (1989) Mass-balance Study: Effect on Mean Soil Ingestion Estimate (mg/day)[a]

	Negative Error						
	Lack of Fecal Sample on Final Study Day	Other Causes[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

* 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

methodologies were employed to identify differences in the recoveries of the various tracers (Sedman and Mahmood, 1994).

From the adult studies, the ANOVA of the natural logarithm of the recoveries of tracers from 0.3 or 1.5 g of ingested soil showed a significant difference (α =0.05) among the estimates of recovery of the tracers regardless of whether the recoveries were combined or analyzed separately (Sedman and Mahmood, 1994). Sedman and Mahmood (1994) also reported that barium, manganese, and zirconium yielded significantly different estimates of soil ingestion than the other tracers (aluminum, silicon, yttrium, titanium, and vanadium). Table 4-13 presents the Tukey's multiple comparison of mean log tracer recovery in adults ingesting known quantities of soil.

The average ages of children in the two recent studies were 2.4 years in Calabrese, et al. (1989) and 4.7 years in Davis et al. (1990). The mean of the adjusted levels of soil ingestion for a two year old child was 220 mg/kg for the Calabrese et al. (1989) study and 170 mg/kg for the Davis et al. (1990) study (Sedman and Mahmood, 1994). From the adjusted soil ingestion estimates, based on a normal distribution of means, the mean estimate for a 2-year old child was 195 mg/day and the overall mean of soil ingestion and the standard error of the mean was 53 mg/day (Sedman and Mahmood, 1994). Based on uncertainties associated with the method employed, Sedman and Mahmood (1994) recommended a conservative estimate of soil ingestion in young children of 250 mg/day. Based on the 250 mg/day ingestion rate in a 2-year old child, an average daily soil ingestion over a lifetime was estimated to be 70 mg/day. The lifetime estimates were derived using the equation presented above that describes changes in soil ingestion with age (Sedman and Mahmood, 1994).

AIHC Exposure Factors Sourcebook (1994) - The Exposure Factors Sourcebook (AIHC, 1994) uses data from the Calabrese et al. (1990) study to derive soil ingestion rates using zirconium as the tracer. More recent papers indicate that zirconium is not a good tracer. Therefore, the values recommended in the AIHC Sourcebook are not appropriate. Furthermore, because individuals were only studied for a short period of time, deriving a distribution of usual intake is not possible and is inappropriate.

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 to be the following:

- Ingestion of high levels of tracers before the study starts and low ingestion during study period may result in over estimation of soil ingestion; and

- Ingestion of element tracers from a non-food or non-soil source during the study period.

Table 4-13 Tukey's Multiple Comparison of Mean Log Tracer Recovery in Adults Ingesting Known Quantities of Soil

Tracer	Reported Mean (mg/day)	Age Adjusted Mean (mg/day)
	Calabrese et al., 1989 Study	
Aluminum	153	160
Silicon	154	161
Titanium	218	228
Vanadium	459	480
Yttrium	85	89
	Davis et al., 1990 Study	
Aluminum	39	53
Silicon	81	111
Titanium	246	333

* Age adjusted mean estimates of soil ingestion in young children. Mean estimates of soil ingestion for each tracer in each study were adjusted using the following equation:

$Y = x\,e^{(-0.112 * yr)}$, where Y = adjusted mean soil ingestion (mg/day), x = a constant, and yr = age in years

Source: Sedman and Mahmood, 1994

Table 4-12. Estimated Soil Ingestion Rate Summary Statistics and Parameters for Distributions Using Binder et al. (1986) Data with Actual Fecal Weights

Trace Element Basis	Soil Intake (mg/day)			
	Al	Si	Ti	MEAN[a]
Mean	97	85	1,004	91
Min	11	10	1	13
10th	21	19	3	22
20th	33	23	22	34
30th	39	36	47	43
40th	43	52	172	49
Med	45	60	293	59
60th	55	65	475	69
70th	73	79	724	92
80th	104	106	1,071	100
90th	197	166	2,105	143
Max	1,201	642	14,061	921
	Lognormal Distribution Parameters			
Median	45	60	–	59
Standard Deviation	169	95	–	126
Arithmetic Mean	97	85	–	91
	Underlying Normal Distribution Parameters			
Mean	4.06	4.07	–	4.13
Standard Deviation	0.88	0.85	–	0.80

[a] MEAN = arithmetic average of soil ingestion based on aluminum and silicon.
Source: Thompson and Burmaster, 1991

medicine and the results may not be representative of long-term intake rates because the data were derived from a short-term study.

Sedman and Mahmood (1994) - Soil Ingestion by Children and Adults Reconsidered Using the Results of Recent Tracer Studies - Sedman and Mahmood (1994) used the results of two recent children's (Calabrese et al. 1989; Davis et al. 1990) tracer studies to determine estimates of average daily soil ingestion in young children and for over a lifetime. In the two studies, the intake and excretion of a variety of tracers were monitored, and concentrations of tracers in soil adjacent to the children's dwellings were determined (Sedman and Mahmood, 1994). From a mass balance approach, estimates of soil ingestion in these children were determined by dividing the excess tracer intake (i.e., quantity of tracer recovered in the feces in excess of the measured intake) by the average concentration of tracer in soil samples from each child's dwelling. Sedman and Mahmood (1994) adjusted the mean estimates of soil ingestion in children for each tracer (Y) from both studies to reflect that of a 2-year old child using the following equation:

$$Y_1 = x\, e^{(-0.112 \cdot yr)} \qquad \text{(Eqn. 4-3)}$$

where:

Y_1 = adjusted mean soil ingestion (mg/day)
x = a constant
yr = average age (2 years)

In addition to the study in young children, a study (Calabrese et al., 1989) in adults was conducted to evaluate the tracer methodology. In the adult studies, percent recoveries of tracers were determined in six adults who ingested known quantities of tracers in 1.5 or 0.3 grams of soil. The distribution of tracer recoveries from adults was evaluated using data analysis techniques involving visualization and exploratory data analysis (Sedman and Mahmood, 1994). From the results obtained in these studies, the distribution of tracer recoveries from adults were determined. In addition, an analysis of variance (ANOVA) and Tukey's multiple comparison

Table 4-11. Estimates of Soil Ingestion for Children

Scenarios	Media	Exposure (mg/day)	Days/Year Activity	Fraction Soil Content	Annual Average Soil Intake (mg/day)
Young Child (2.5 Years Old)					
Outdoor Activities (Summer)	Soil	250	130	1	90
Indoor Activities (Summer)	Dust	50	182	0.8	20
Indoor Activities (Winter	Dust	100	182	0.8	40
TOTAL SOIL INTAKE					150
Older Child (6 Years Old)					
Outdoor Activities (Summer)	Soil	50	152	1	21
Indoor Activities (Year-Round)	Dust	3	365	0.8	2.4
TOTAL SOIL INTAKE					23.4

Source: Hawley, 1985

fingers on one hand while playing outdoors. This assumption was based on data from Lepow et al. (1975). Outdoor activities were assumed to occur each day over 5 months of the year (i.e., during May through October). These children were also assumed to ingest 3 mg/day of housedust from the indoor surfaces of the hands during indoor activities occurring over the entire year. Using these data, Hawley (1985) estimated the annual average soil intake rate for older children to be 23.4 mg/day (Table 4-11).

Thompson and Burmaster (1991) - Parametric Distributions for Soil Ingestion by Children - Thompson and Burmaster (1991) developed parameterized distributions of soil ingestion rates for children based on a reanalysis of the data collected by Binder et al. (1986). In the original Binder et al. (1986) study, an assumed fecal weight of 15 g/day was used. Thompson and Burmaster reestimated the soil ingestion rates from the Binder et al. (1986) study using the actual stool weights of the study participants instead of the assumed stool weights. Because the actual stool weights averaged only 7.5 g/day, the soil ingestion estimates presented by Thompson and Burmaster (1991) are approximately one-half of those reported by Binder et al. (1986). Table 4-12 presents the distribution of estimated soil ingestion rates calculated by Thompson and Burmaster (1991) based on the three tracers elements (i.e., aluminum, silicon, and titanium), and on the arithmetic average of soil ingestion based on aluminum and silicon. The mean soil intake rates were 97 mg/day for aluminum, 85 mg/day for silicon, and 1,004 mg/day for titanium. The 90th percentile estimates were 197 mg/day for aluminum, 166 mg/day for silicon, and 2,105 mg/day for titanium. Based on the arithmetic average of aluminum and silicon for each child, mean soil intake was estimated to be 91 mg/day and 90th percentile intake was estimated to be 143 mg/day.

Thompson and Burmaster (1991) tested the hypothesis that soil ingestion rates based on the adjusted Binder et al. (1986) data for aluminum, silicon and the average of these two tracers were lognormally distributed. The distribution of soil intake based on titanium was not tested for lognormality because titanium may be present in food in high concentrations and the Binder et al. (1986) study did not correct for food sources of titanium (Thompson and Burmaster, 1991). Although visual inspection of the distributions for aluminum, silicon, and the average of these tracers all indicated that they may be lognormally distributed, statistical tests indicated that only silicon and the average of the silicon and aluminum tracers were lognormally distributed. Soil intake rates based on aluminum were not lognormally distributed. Table 4-12 also presents the lognormal distribution parameters and underlying normal distribution parameters (i.e., the natural logarithms of the data) for aluminum, silicon, and the average of these two tracers. According to the authors, "the parameters estimated from the underlying normal distribution are much more reliable and robust" (Thompson and Burmaster, 1991).

The advantages of this study are that it provides percentile data and defines the shape of soil intake distributions. However, the number of data points used to fit the distribution was limited. In addition, the study did not generate "new" data. Instead, it provided a reanalysis of previously-reported data using actual fecal weights. No corrections were made for tracer intake from food or

observations. It also corrects for biases associated with the differences in tracer metabolism. The limitations associated with the data used in this study are the same as the limitations described in the summaries of the Calabrese et al. (1989), Davis et al. (1990) and Calabrese et al. (1990) studies.

4.3. RELEVANT STUDIES ON SOIL INTAKE AMONG CHILDREN

Lepow et al. (1975) - Investigations Into Sources of Lead in the Environment of Urban Children - Lepow et al. (1975) used data from a previous study (Lepow et al., 1974) to estimate daily soil ingestion rates of children. Lepow et al. (1974) estimated ingestion of airborne lead fallout among urban children by: (1) analyzing surface dirt and dust samples from locations where children played; (2) measuring hand dirt by applying preweighed adhesive labels to the hands and weighing the amount of dirt that was removed; and (3) observing "mouthing" behavior over 3 to 6 hours of normal play. Twenty-two children from an urban area of Connecticut were included in the study. Lepow et al. (1975) used data from the 1974 study and found that the mean weight of soil/dust on the hands was 11 mg. Assuming that a child would put fingers or other "dirty" objects into his mouth about 10 times a day ingesting 11 mg of dirt each time, Lepow et al. (1975) estimated that the daily soil ingestion rate would be about 100 mg/day. According to Lepow et al. (1975), the amount of hand dirt measured with this technique is probably an underestimate because dirt trapped in skin folds and creases was probably not removed by the adhesive label. Consequently, mean soil ingestion rates may be somewhat higher than the values estimated in this study.

Day et al. (1975) - Lead in Urban Street Dust - Day et al. (1975) evaluated the contribution of incidental ingestion of lead-contaminated street dust and soil to children's total daily intake of lead by measuring the amount of lead in street dust and soil and estimating the amount of dirt ingested by children. The amount of soil that might be ingested was estimated by measuring the amount of dirt that was transferred to a "sticky sweet" during 30 minutes of play and assuming that a child might eat from 2 to 20 such sweets per day. Based on "a small number of direct measurements," Day et al. (1975) found that 5 to 50 mg of dirt from a child's hands may be transferred to a "sticky sweet" during 30 minutes of "normal playground activity. Assuming that all of the dirt is ingested with the 2 to 20 "sticky sweets," Day et al. (1975) estimated that intake of soil among children could range from 10 to 1000 mg/day.

Duggan and Williams (1977) - Lead in Dust in City Streets - Duggan and Williams (1977) assessed the risks associated with lead in street dust by analyzing street dust from areas in and around London for lead, and estimating the amount of hand dirt that a child might ingest. Duggan and Williams (1977) estimated the amount of dust that would be retained on the forefinger and thumb by removing a small amount of dust from a weighed amount, rubbing the forefinger and thumb together, and reweighing to determine the amount retained on the finger and thumb. The results of "a number of tests with several different people" indicated that the mean amount of dust retained on the finger and thumb was approximately 4 mg with a range of 2 to 7 mg (Duggan and Williams, 1977). Assuming that a child would suck his/her finger or thumb 10 times a day and that all of the dirt is removed each time and replaced with new dirt prior to subsequent mouthing behavior, Duggan and Williams (1977) estimated that 20 mg of dust would be ingested per day.

Hawley et al. (1985) - Assessment of Health Risk from Exposure to Contaminated Soil - Using existing literature, Hawley (1985) developed scenarios for estimating exposure of young children, older children, and adults to contaminated soil. Annual soil ingestion rates were estimated based on assumed intake rates of soil and housedust for indoor and outdoor activities and assumptions about the duration and frequency of the activities. These soil ingestion rates were based on the assumption that the contaminated area is in a region having a winter season. Housedust was assumed to be comprised of 80 percent soil.

Outdoor exposure to contaminated soil among young children (i.e., 2.5 years old) was assumed to occur 5 days per week during only 6 months of the year (i.e., mid-April through mid-October). Children were assumed to ingest 250 mg soil/day while playing outdoors based on data presented in Lepow et al. (1974; 1975) and Roels et al. (1980). Indoor exposures among this population were based on the assumption that young children ingest 100 mg of housedust per day while spending all of their time indoors during the winter months, and 50 mg of housedust per day during the warmer months when only a portion of their time is spent indoors. Based on these assumptions, Hawley (1985) estimated that the annual average soil intake rate for young children is 150 mg/day (Table 4-11). Older children (i.e., 6 year olds) were assumed to ingest 50 mg of soil per day from an area equal to the area of the

Table 5-10. Comparisons of Estimated Basal Metabolic Rates (BMR) with Average Food-Energy Intakes for Individuals Sampled in the 1977-78 NFCS

Cohort/Age	Body Weight	BMR[a]		Energy Intake (EFD)		Ratio
(years)	kg	MJ d^{-1}[b]	kcal d^{-1}[c]	MJ d^{-1}	kcal d^{-1}	EFD/BMR
Children						
Under 1	7.6	1.74	416	3.32	793	1.90
1 to 2	13	3.08	734	5.07	1209	1.65
3 to 5	18	3.69	881	6.14	1466	1.66
6 to 8	26	4.41	1053	7.43	1774	1.68
Males						
9 to 11	36	5.42	1293	8.55	2040	1.58
12 to 14	50	6.45	1540	9.54	2276	1.48
15 to 18	66	7.64	1823	10.8	2568	1.41
19 to 22	74	7.56	1804	10.0	2395	1.33
23 to 34	79	7.87	1879	10.1	2418	1.29
35 to 50	82	7.59	1811	9.51	2270	1.25
51 to 64	80	7.49	1788	9.04	2158	1.21
65 to 74	76	6.18	1476	8.02	1913	1.30
75 +	71	5.94	1417	7.82	1866	1.32
Females						
9 to 11	36	4.91	1173	7.75	1849	1.58
12 to 14	49	5.64	1347	7.72	1842	1.37
15 to 18	56	6.03	1440	7.32	1748	1.21
19 to 22	59	5.69	1359	6.71	1601	1.18
23 to 34	62	5.88	1403	6.72	1603	1.14
35 to 50	66	5.78	1380	6.34	1514	1.10
51 to 64	67	5.82	1388	6.40	1528	1.10
65 to 74	66	5.26	1256	5.99	1430	1.14
75 +	62	5.11	1220	5.94	1417	1.16

[a] Calculated from the appropriate age and gender-based BMR equations given in Appendix Table 5A-4.
[b] MJ d^{-1} - mega joules/day
[c] kcal d^{-1} - kilo calories/day
Source: Layton, 1993

source of uncertainty in the inhalation rates estimated. An advantage is that this study provides empirical data useful in exposure assessments for a subpopulation thought to be the most highly exposed common occupational group (outdoor workers).

Layton (1993) - Metabolically Consistent Breathing Rates for Use in Dose Assessments - Layton (1993) presented a new 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 (Layton, 1993). However, in this study, breathing rates were calculated based on 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:

$$V_E = E \times H \times VQ \qquad \text{(Eqn. 5-3)}$$

where:

- V_E = ventilation rate (L/min or m^3/hr);
- E = energy expenditure rate; [kilojoules/minute (KJ/min) or megajoules/hour (MJ/hr)];
- H = volume of oxygen [at standard temperature and pressure, dry air (STPD) 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 (L/min) to oxygen uptake (L/min)) unitless.

Three alternative approaches were used to estimate daily chronic (long term) inhalation rates for different age/gender cohorts of the U.S. population using this methodology.

First Approach

Inhalation rates were estimated by multiplying average daily food energy intakes for different age/gender cohorts, volume of oxygen (H), and ventilatory equivalent (VQ), as shown in the equation above. The average food energy intake data (Table 5-10) are based on approximately 30,000 individuals and were obtained from the USDA 1977-78 Nationwide Food Consumption Survey (USDA-NFCS). The food energy intakes were adjusted upwards by a constant factor of 1.2 for all individuals 9 years and older (Layton, 1993). This factor compensated for a consistent bias in USDA-NFCS 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 1977-78 USDA-NFCS and the second National Health and Nutrition Examination Survey (NHANES II). The survey sample for NHANES II was approximately 20,000 participants. The ventilatory equivalent (VQ) of 27 used was calculated as the geometric mean of VQ data that were obtained from several studies by Layton (1993).

The inhalation rate estimation techniques are shown in footnote (a) of Table 5-11. Table 5-11 presents the daily inhalation rate for each age/gender cohort. The highest daily inhalation rates were reported for children between the ages of 6-8 years (10 m^3/day), for males between 15-18 years (17 m^3/day), and females between 9-11 years (13 m^3/day). Estimated average lifetime inhalation rates for males and females are 14 m^3/day and 10 m^3/day, respectively (Table 5-11). Inhalation rates were also calculated for active and inactive periods for the various age/gender cohorts.

The inhalation rate for inactive periods was estimated by multiplying the basal metabolic rate (BMR) times the oxygen uptake (H) times the 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 5-11. These data for active and inactive inhalation rates are also presented in Table 5-11. For children, inactive and active inhalation rates ranged between 2.35 and 5.95 m^3/day and 6.35 to 13.09 m^3/day, respectively. For adult males (19-64 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 (19-64 years old) were approximately 8 and 12 m^3/day, respectively.

Second Approach

Inhalation rates were calculated by multiplying the BMR of the population cohorts times A (ratio of total daily energy expenditure to daily BMR) times H times VQ. The BMR data obtained from literature were statistically analyzed and regression equations were developed to predict BMR from body weights of various age/gender cohorts (Layton, 1993). The statistical data used to develop the regression equations are presented in Appendix Table 5A-4. The data obtained from the second

Table 5-8. Distributions of Individual and Group Inhalation/Ventilation Rate for Outdoor Workers

		Ventilation Rate (VR) (m^3/hr)		
		Percentile		
Population Group and Subgroup[a]	Mean ± SD	1	50	99
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 5-9. Individual Mean Inhalation Rate (m^3/hr) by Self-Estimated Breathing Rate or Job Activity Category for Outdoor Workers

	Self-Estimated Breathing Rate (m^3/hr)			Job Activity Category (m^3/hr)			
Population Group and Subgroup	Slow	Med	Fast	Sit/Std	Walk	Carry	Trade[b]
All Subjects (n=19)	1.44	1.86	2.04	1.56	1.80	2.10	1.92
Job							
GCW[a]/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=7)	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 GCW - general construction worker
b Trade - "Working at Trade" (i.e., tasks specific to the individual's job classification)
Source: Linn et al., 1993

Therefore, it was necessary to predict IR 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

Table 5-7. Summary of Average Inhalation Rates (m^3/hr) by Age Group and Activity Levels in Field Protocols

Age Group	Light[a]	Sedentary[b]	Moderate[c]
Young Children[d]	DNP[e]	DNP	0.68
Children[f]	DNP	DNP	1.07
Adult Females[g]	1.10[h]	0.51	DNP
Adult Males[i]	1.40	0.62	1.79[j]

[a] Light activity was defined as car maintenance (males), housework (females), and yard work (females) (see Appendix Table 5A-2 for original data).
[b] Sedentary activity was defined as car driving and riding (both genders) (see Appendix Table 5A-2 for original data).
[c] Moderate activity was defined as mowing (males); wood working (males); yard work (males); and play (children) (see Appendix Table 5A-2 for original data).
[d] Young children (both genders) = 3 - 5.9 yrs old.
[e] DNP: Group did not perform this protocol or N was too small for appropriate mean comparisons.
[f] Children (both genders) = 6 - 12.9 yrs old.
[g] Adult females defined as adolescent, young to middle aged, and older adult females.
[h] Older adults not included in mean value since they did not perform this activity.
[i] Adult males defined as adolescent, young to middle aged, and older adult males.
[j] Adolescents not included in mean value since they did not perform this activity.
Source: Adams, 1993

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). Summary statistics for predicted VR distributions for all subjects, and for job or site defined subgroups are presented in Table 5-8. The data reflect all recordings before and during work, and at break times. For all subjects, the mean IR was 1.68 m^3/hr with a standard deviation of ±0.72 (Table 5-8). Also, for most subjects, the 1st and 99th percentiles of HR were outside of the calibration range (calibration ranges are presented in Appendix Table 5A-3). Therefore, corresponding IR percentiles were extrapolated using the calibration data (Linn et al., 1993).

The data presented in Table 5-9 represent distribution patterns of IR for each subject, total subjects, and job or site defined subgroups by self-estimated breathing rates (slow, medium, 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 (Table 5-9). In spite of their higher predicted VR workers at the hospital site reported a higher percentage of slow breathing time (31 percent) than workers at the office site (20 percent), and a lower percentage of fast breathing time, 3 percent and 5 percent, 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.

A limitation associated with this study is the small sample size. Another limitation of this study is that calibration data were not obtained at extreme conditions.

mowing protocols. HR, VR, and f_R 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, IR for the children's group revealed no significant gender differences, but those for the adult groups demonstrated gender differences. Therefore, IR data presented in Appendix Tables 5A-1 and 5A-2 were categorized as young children, children (no gender),and for adult female, and adult male by activity levels (resting, sedentary, light, moderate, and heavy). These categorized data from the Appendix tables are summarized as IR in m^3/hr in Tables 5-6 and 5-7. The laboratory protocols are shown in Table 5-6. Table 5-7 presents the mean inhalation rates by group and activity levels (light, sedentary, and moderate) in field protocols. A comparison of the data shown in Tables 5-6 and 5-7 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 IR across all population groups and activity types were obtained by including body surface area (BSA), HR, and f_R in multiple regression analysis (Adams, 1993). Adams (1993) calculated BSA from measured height and weight using the equation:

$$BSA = Height^{0.725} \times Weight^{0.425} \times 71.84 \qquad \text{(Eqn. 5-2)}$$

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/gender cohorts. The estimated rates were based on short-term data and may not reflect long-term patterns. An advantage of this study is that it provides inhalation data for all age groups.

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

Table 5-6. Summary of Average Inhalation Rates (m^3/hr) by Age Group and Activity Levels for Laboratory Protocols

Age Group	Resting[a]	Sedentary[b]	Light[c]	Moderate[d]	Heavy[e]
Young Children[f]	0.37	0.40	0.65	DNP[g]	DNP
Children[h]	0.45	0.47	0.95	1.74	2.23
Adult Females[i]	0.43	0.48	1.33	2.76	2.90[j]
Adult Males[k]	0.52	0.60	1.45	1.93	3.63

a Resting defined as lying (see Appendix Table 5A-1 for original data)
b Sedentary defined as sitting and standing (see Appendix Table 5A-1 for original data)
c Light defined as walking at speed level 1.5 - 3.0 mph (see Appendix Table 5A-1 for original data)
d Moderate defined as fast walking (3.3 - 4.0 mph) and slow running (3.5 - 4.0 mph) (see Appendix Table 5A-1 for original data)
e Heavy defined as fast running (4.5 - 6.0 mph) (see Appendix Table 5A-1 for original data)
f Young children (both genders) 3 - 5.9 yrs old.
g DNP: Group did not perform this protocol or N was too small for appropriate mean comparisons. All young children did not run.
h Children (both genders) 6 - 12.9 yrs old.
i Adult females defined as adolescent, young to middle aged, and older adult females.
j Older adults not included in mean value since they did not perform running protocols at particular speeds
k Adult males defined as adolescent, young to middle aged, and older adult males.

Source: Adapted from Adams, 1993

Table 5-5 Distribution Patterns of Daily Inhalation Rates for Elementary (EL) and High School (HS) Students Grouped by Activity Level

Students	Age (yrs)	Location	Activity type[a]	Mean IR[b] (m^3/day)	Percentile Rankings 1st	50th	99.9th
EL (n^c=17)	10-12	Indoor	Light	13.7	2.93	12.71	38.14
			Moderate	2.8	0.70	2.44	7.48
			Heavy	0.4	0.096	0.34	1.37
EL		Outdoor	Light	2.1	0.79	1.72	9.50
			Moderate	1.84	0.41	1.63	5.71
			Heavy	0.57	0.24	0.48	1.80
HS (n=19)	13-17	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	0.50	1.08	6.34
			Moderate	1.64	0.62	1.40	7.41
			Heavy	0.29	0.006	0.20	1.19

[a] For this report, activity type presented in Table 5-2 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 (Table 5-4) by the corresponding inhalation rate (Table 5-3).

[c] Number of elementary (EL) and high school students (HS).

Source: Adapted from Spier et al., 1992 (Generated using data from Tables 5-3 and 5-4).

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. These data are useful in estimating exposure for the younger population.

Adams (1993) - Measurement of Breathing Rate and Volume in Routinely Performed Daily Activities - Adams (1993) conducted research to accomplish two main objectives: (1) identification of mean and ranges of inhalation rates for various age/gender cohorts and specific activities; and (2) derivation of simple linear and multiple regression equations used to predict inhalation rates through other measured variables: heart rate (HR), breathing frequency (f_B), and oxygen consumption (V_{O2}). 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 years old and 12 young children from 3 to 5 years old were identified as subjects for pilot testing purposes in this age group (Adams, 1993).

Resting protocols conducted in the laboratory for all age groups consisted of three phases (25 minutes each) of lying, sitting, and standing. They 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 intensities made up of 6 minute intervals, at 3 speeds, ranging from slow to moderately fast. All protocols involved measuring VR, HR, f_B (breathing frequency), and V_{O2} (oxygen consumption). 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, while the older adolescent population (16-18 years) completed car driving and riding, car maintenance (males), and housework (females) protocols. All adult females (19-60 years) and most of the senior (60-77 years) females completed housework, yardwork, and car driving and riding protocols. Adult and senior males completed car driving and riding, yardwork, and

Table 5-3. Distribution of Predicted IR by Location and Activity Levels for Elementary and High School Students

Age (yrs)	Student	Location	Activity Level	% Recorded Time[a]	Inhalation Rates (m^3/hr) Mean ± SD	Percentile Rankings[b] 1st	50th	99.9th
10-12	EL[c] (n[d]=17)	Indoors	slow	49.6	0.84 ± 0.36	0.18	0.78	2.34
			medium	23.6	0.96 ± 0.42	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] (n[d]=19)	Indoors	slow	70.7	0.78 ± 0.36	0.30	0.72	3.24
			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 hr per elementary school student and 33 hr. per high school student, over 72-hr. 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] EL = elementary school student; HS = high school student.
[d] N = number of students that participated in survey.
[e] Highest single value.

Source: Spier et al., 1992.

Table 5-4. Average Hours Spent Per Day in a Given Location and Activity Level for Elementary (EL) and High School (HS) Students

Student (EL[a] n[c]=17; HS[b] N[c]=19)	Location	Activity Level: Slow	Medium	Fast	Total Time Spent (hrs/day)
EL	Indoor	16.3	2.9	0.4	19.6
EL	Outdoor	2.2	1.7	0.5	4.4
HS	Indoor	19.5	1.5	0.2	21.2
HS	Outdoor	1.2	1.3	0.2	2.7

[a] Elementary school (EL) students were between 10-12 years old.
[b] High school (HS) students were between 13-17 years old.
[c] N corresponds to number of school students.

Source: Spier et al., 1992.

Table 5-2. Subject Panel Inhalation Rates by Mean VR, Upper Percentiles, and Self-Estimated Breathing Rates

Panel	Inhalation Rates (m^3/hr)					
	N[a]	Mean VR (m^3/hr)	99th Percentile VR	Mean VR at Activity Levels (m^3/hr)[b]		
				Slow	Medium[c]	Fast[c]
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[d]	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.

Source: Linn et al. 1992

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 calibrated. Another limitation of this study is the small sample size of each subpopulation 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 subpopulations (i.e., healthy outdoor adult workers, healthy children, asthmatics, and construction workers).

Spier et al. (1992) - Activity Patterns in Elementary and High School Students Exposed To Oxidant Pollution - Spier et al. (1992) investigated 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 for each: 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, change 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 during the 3 days once per minute by wearing 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 presented in Table 5-3 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 hours spent indoors by high school students (21.2 hours) were higher 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 (Table 5-4). Based on the data presented in Tables 5-3 and 5-4, the average activity-specific inhalation rates for elementary (10-12 years) and high school (13-17 years) students were calculated in Table 5-5. For elementary school students, the average daily inhalation rates (based on indoor and outdoor locations) are 15.8 m^3/day for light activities, 4.62 m^3/day for moderate activities, and 0.98 m^3/day for heavy activities. For high school students the daily inhalation rates for light, moderate, and heavy activities are estimated to be 16.4 m^3/day, 3.1 m^3/day, and 0.54 m^3/day, respectively (Table 5-5).

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); *Panel 7*: construction workers (7 males, ages 26-34 years).

Initially, a calibration test was conducted, followed by a training session. Finally, a field study was conducted which involved subjects' collecting their own heart rate and diary data. During the calibration tests, VR 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 (Linn et al., 1992).

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. Asthmatic subjects recorded their diary information once every hour using a Heart Watch. Construction workers dictated their diary information to a technician accompanying them on the job. 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 5-1 presents the calibration and field protocols for self-monitoring of activities for each subject panel.

Table 5-2 presents the mean VR, the 99th percentile VR, and the mean VR at each subjective activity level (slow, medium, fast). The mean VR 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 (Linn et al., 1992). The mean VR for healthy adults was 0.78 m^3/hr while the mean VR for asthmatic adults was 1.02 m^3/hr (Table 5-2). The preliminary data for construction workers indicated that during a 10-hr work shift, their mean VR (1.50 m^3/hr) exceeded the VRs of all other subject panels (Table 5-2). Linn et al. (1992) reported that the diary data showed that most individuals except construction workers spent most of their time (in a typical day) indoors at slow activity level. During slow activity, asthmatic subjects had higher VRs than healthy subjects, except construction workers (Table 5-2). Also, Linn et al. (1992) reported that in every panel, the predicted VR correlated significantly with the subjective estimates of activity levels.

Table 5-1 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, age 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; HR recordings and activity diary during waking hours and during sleep.
Panel 3 - Healthy High School Students - 7 male, 12 female, age 13-17	Outdoor exercises each consisted of 20 minute rest, slow walking, jogging and fast walking	Same as Panel 2, however, no HR 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, age 11-16	Laboratory exercise tests on bicycles and treadmills	Similar to Panel 4, 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

absorbed into the blood stream or react with lung tissue. Gases can be removed from the lung by reaction with tissues or by expiration. The amount of gas retained in the lung or other parts of the body is mainly due to their solubility in blood.

Chemically, particles are quite heterogenous. They range from aqueous soluble particles to solid insoluble particles. Their size, chemical composition, and the physical forces of breathing dictate where they tend to deposit in the lung. Large particles, those with a diameter of greater than 0.5 micrometers (um), not filtered out in the nasopharynx, tend to deposit in the upper respiratory tract at airway branching points due to impaction. The momentum of these particles in the air stream is such that they tend to collide with the airway wall at branching points in the tracheobronchial region of the lung. Those particles not removed from the airstream by impaction will likely be deposited in small bronchi and bronchioles by sedimentation, a process where by particles settle out of the airstream due to the decrease in airstream velocity and the gravitational force on the particles. Small particles, less than 0.2 um, acquire a random motion due to bombardment by air molecules. This movement can cause particles to be deposited on the wall of an air way throughout the lungs.

A special case exists for fibers. Fibers can deposit along the wall of an airway by a process known as interception. This occurs when a fiber makes contact with an airway wall. The likelihood of interception increases as airway diminish in diameter. Fiber shape influences deposition too. Long, thin, straight fibers tend to deposit in the deep region of the lung compared to thick or curved fibers.

The health risk associated with human exposure to airborne toxics is a function of concentration of air pollutants, chemical species, duration of exposure, and inhalation rate. The dose delivered to target organs (including the lungs) , the biologically effective dose, is dependent on the potentail dose, the applied dose and the internal dose (Figure 5-1) A detailed discussion of this concept can be found in Guidelines for Exposure Assessment (U.S. EPA, 1992).

The estimation of applied dose for a given air pollutant is dependent on inhalation rate, commonly described as ventilation rate (VR) or breathing rate. VR is usually measured as minute volume, the volume in liters of air exhaled per minute(V_E). V_E is the product of the number of respiratory cycles in a minute and the volume of air respired during each respiratory cycle, the tidal volume(V_T).

When interested in calculating internal dose, assessors must consider the alveolar ventilation rate. This is the amount of air available for exchange with alveoli per unit time. It is equivalent to the tidal volume(V_T) minus the anatomic dead space of the lungs (the space containing air that does not come into contact with the alveoli). Alveolar ventilation is approximately 70 percent of total ventilation: tidal volume is approximately 500 milliliters (ml) and the amount of anatomic dead space in the lungs is approximately 150 ml, approximately 30% of the amount of air inhaled (Menzel and Amdur, 1986).

Breathing rates are affected by numerous individual characteristics, including age, gender, weight, health status, and levels of activity (running, walking, jogging, etc.). VRs are either measured directly using a spirometer and a collection system or indirectly from heart rate (HR) measurements. In many of the studies described in the following sections, HR measurements are usually correlated with VR in simple and multiple regression analysis.

The available studies on inhalation rates are summarized in the following sections. Inhalation rates are reported for adults and children (including infants) performing various activities and outdoor workers/ athletes. The activity levels have been categorized as resting, sedentary, light, moderate, and heavy. In most studies, the sample population kept diaries to record their physical activities, locations, and breathing rates. Ventilation rates were either measured, self-estimated or predicted from equations derived using VR-HR calibration relationships.

5.2.2. Key Inhalation Rate Studies

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" subpopulation groups exposed to ozone (O_3) 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

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 to 11 m^3/day, 9.9 to 11 m^3/day, and 11 to 15 m^3/day, for the first, second, and third approach, respectively. The inhalation rates for adult males ranged from 13 to 16 m^3/day for the first approach, and 13 to 17 m^3/day for the second and third approaches.

Inhalation rates were also obtained for short-term exposures for various age/gender cohorts and five energy-expenditure categories (rest, sedentary, light, moderate, and heavy). BMRs were multiplied by the product of MET, H, and VQ. The data obtained for short term exposures are presented in Table 5-14.

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 that activity pattern levels estimated in this study are somewhat subjective, the explanation that activity pattern differences is responsible for the lower level obtained with the metabolic approach (25 percent) compared to the activity pattern approach is not well supported by the data, and different populations were used in each approach which may introduce error.

5.2.3. Relevant Inhalation Rate Studies

International Commission on Radiological Protection (ICRP) (1981) - Report of the Task Group on Reference Man - The International Commission of Radiological Protection (ICRP) estimated daily inhalation rates for reference adult males, adult females, children (10 years old), infant (1 year old), and newborn babies by using a time-activity-ventilation approach. This approach for estimating 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. ICRP (1981) compiled reference values (Appendix Table 5A-5) of minute volume/inhalation rates from various literature sources. ICRP (1981) assumed that the daily activities of a reference man and woman, and child (10 yrs) consisted of

Table 5-14. Inhalation Rates for Short-Term Exposures

Gender/Age (yrs)	Weight (kg)[a]	BMR[b] (MJ/day)	Activity Type: Rest	Sedentary	Light	Moderate	Heavy
			MET (BMR Multiplier)				
			1	1.5	3[c]	5[d]	10[e]
			Inhalation Rate (m^3/hr)[f]				
Male							
0.5 - <3	14	3.40	0.19	0.23	0.38	0.78	1.92
3 - <10	23	4.30	0.24	0.29	0.49	0.99	2.40
10 - <18	53	6.70	0.38	0.45	0.78	1.50	3.78
18 - <30	76	7.70	0.43	0.52	0.84	1.74	4.32
30 - <60	80	7.50	0.42	0.50	0.86	1.68	4.20
60+	75	6.10	0.34	0.41	0.66	1.38	3.42
Female							
0.5 - <3	11	2.60	0.14	0.17	0.29	0.60	1.44
3 - <10	23	4.10	0.23	0.27	0.45	0.90	2.28
10 - <18	50	5.70	0.32	0.38	0.66	1.26	3.18
18 - <30	62	5.90	0.33	0.40	0.66	1.32	3.30
30 - <60	68	5.80	0.32	0.39	0.66	1.32	3.24
60+	67	5.40	0.30	0.36	0.59	1.20	3.00

[a] Body weights were based on average weights for age/gender cohorts of the U.S. population
[b] The BMRs for the age/gender cohorts were calculated using the respective body weights and the BMR equations (Appendix Table 5A-4)
[c] Range of 1.5 - 2.5
[d] Range of 3 - 5
[e] Range of >5 - 20
[f] The inhalation rate was calculated by multiplying BMR (MJ/day) x [(0.05 EK) x MET x VQ (27)] x (d/1,440 min)
[g] Original data were presented in l/min. Conversion to m^3/hr was obtained as follows

$$\frac{\text{ml/min}}{\text{hr}} \times \frac{\text{m}^3}{1000\text{L}} \times \frac{\text{L}}{\text{min}}$$

Source: Layton, 1993

Table 5-13. Daily Inhalation Rates Based on Time-Activity Survey

Age (yrs) and Activity	MET	Males						Females					
		Body Weight[a] (kg)	BMR[b] (KJ/hr)	Duration[c] (hr/day)	E[d] (MJ/day)	V_E[e] (m^3/day)	V_E[f] (m^3/hr)	Body Weight[a] (kg)	BMR[b] (KJ/hr)	Duration[c] (hr/day)	E[d] (MJ/day)	V_E[e] (m^3/day)	V_E[f] (m^3/hr)
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 basal metabolic rates (BMRs) for the age/gender cohorts were calculated using the respective body weights and the BMR equations (Appendix Table 5A-4)
c Duration of activities were obtained from Sallis et al. (1985)
d Energy expenditure rate (E) was calculated by multiplying BMR (KJ/hr) x (MJ/1000 KJ) x duration (hr/day) x 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/hr) was calculated by multiplying BMR (KJ/hr) x (MJ/1000 KJ) x MET x H (0.05 m^3 oxygen/MJ) x VQ (27)

Source: Layton, 1993.

approach are presented in Table 5-12. Inhalation rates for children (6 months - 10 years) ranged from 7.3-9.3 m^3/day for male and 5.6 to 8.6 m^3/day for female children and (10-18 years) was 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/gender cohort. The energy expenditure associated with each level of activity was estimated by multiplying BMRs of each activity level by the metabolic equivalent (MET) and by the time spent per day performing each activity for each age/gender 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 BMRs were estimated using the metabolic equations presented in Appendix Table 5A-4. The body weights were obtained from a study conducted by Najjar and Rowland (1987) which randomly sampled individuals from the U.S. population (Layton, 1993). Table 5-13 presents the inhalation rates (V_E) in m^3/day and m^3/hr 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

Table 5-12 Daily Inhalation Rates Obtained from the Ratios of Total Energy Expenditure to Basal Metabolic Rate (BMR)

Gender/Age (yrs)	Body Weight[a] (kg)	BMR[b] (MJ/day)	VQ	A[c]	H (m^3O/MJ)	Inhalation Rate, V_E (m^3/day)[d]
Male						
0.5 - <3	14	3.4	27	1.6	0.05	7.3
3 - <10	23	4.3	27	1.6	0.05	9.3
10 - <18	53	6.7	27	1.7	0.05	15
18 - <30	76	7.7	27	1.59	0.05	17
30 - <60	80	7.5	27	1.59	0.05	16
60+	75	6.1	27	1.59	0.05	13
Female						
0.5 - <3	11	2.6	27	1.6	0.05	5.6
3 - <10	23	4.0	27	1.6	0.05	8.6
10 - <18	50	5.7	27	1.5	0.05	12
18 - <30	62	5.9	27	1.38	0.05	11
30 - <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/gender cohorts in the U.S. population.
[b] The BMRs (basal metabolic rate) are calculated using the respective body weights and BMR equations (see Appendix Table 5A-4).
[c] The values of the BMR multiplier (EFD/BMR) for those 18 years and older were derived from the Bassons 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 5-11 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 x A x H x VQ. VQ = ventilation equivalent and H = oxygen uptake
Source: Layton, 1993

Table 5-11 Daily Inhalation Rates Calculated from Food-Energy Intakes

Cohort/Age (years)	L[d]	Daily Inhalation Rate[a] (m³/day)	Sleep (h)	MET[b] Value A[e]	F[f]	Inhalation Rates Inactive[c] (m³/day)	Active[c] (m³/day)
Children							
<1	1	4.5	11	1.9	2.7	2.35	6.35
1 - 2	2	6.8	11	1.6	2.2	4.16	9.15
3 - 5	3	8.3	10	1.7	2.2	4.98	10.96
6 - 8	3	10	10	1.7	2.2	5.95	13.09
Males							
9 - 11	3	14	9	1.9	2.5	7.32	18.3
12 - 14	3	15	9	1.8	2.2	8.71	19.16
15 - 18	4	17	8	1.7	2.1	10.31	21.65
19 - 22	4	16	8	1.6	1.9	10.21	19.4
23 - 34	11	16	8	1.5	1.8	10.62	19.12
35 - 50	16	15	8	1.5	1.8	10.25	18.45
51 - 64	14	15	8	1.4	1.7	10.11	17.19
65 - 74	10	13	8	1.6	1.8	8.34	15.01
75+	1	12	8	1.6	1.9	8.02	15.24
Lifetime average[g]		14					
Females							
9 - 11	3	13	9	1.9	2.5	6.63	16.58
12 - 14	3	12	9	1.6	2.0	7.61	15.20
15 - 18	4	12	8	1.5	1.7	8.14	13.84
19 - 22	4	11	8	1.4	1.6	7.68	12.29
23 - 34	11	11	8	1.4	1.6	7.94	12.7
35 - 50	16	10	8	1.3	1.5	7.80	11.7
51 - 64	14	10	8	1.3	1.5	7.86	11.8
65 - 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] Daily inhalation rate was calculated by multiplying the EFD values (see Table 5-10) by H x VQ x (m^3 1,000 L^{-1}) for subjects under 9 years of age and by 1.2 x H x VQ x (m^3 1,000 L^{-1}) (for subjects 9 years of age and older (see text for explanation).
Where:
EFD = Food energy intake (Kcal/day) or (MJ/day)
H = Oxygen uptake = 0.05 LO_2/Kj or 0.21 LO_2/Kcal
VQ = Ventilation equivalent = 27 = geometric mean of VQs (unitless)

[b] MET = Metabolic equivalent

[c] Inhalation rate for inactive periods was calculated as BMR x H x VQ x (d 1,440 min^{-1}) and for active periods by multiplying inactive inhalation rate by F (See footnote f); BMR values are from Table 5-10.
Where:
BMR = Basal metabolic rate (MJ/day) or (kg/hr)

[d] L is the number of years for each age cohort.

[e] For individuals 9 years of age and older, A was calculated by multiplying the ratio for EFD/BMR (unitless) (Table 5-10) by the factor 1.2 (see text for explanation).

[f] 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 (hrs)

[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.

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 percent (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 5-21 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, 4.80 m^3/hr for low, medium, heavy, and very heavy activities, respectively.

Table 5-21. Actual Inhalation Rates Measured at Four Ventilation Levels

Subject	Location	Mean Inhalation Rate* (m^3/hr)*			
		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

* Original data were presented in L/min. Conversion to m^3/hr was obtained as follows:

$$60 \frac{min}{hr} \times \frac{m^3}{1000L} \times \frac{L}{min}$$

Source: Adapted from Shamoo et al., 1992

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.

AIHC (1994) - The Exposure Factors Sourcebook - AIHC (1994) recommends an average adult inhalation rate of 18 m^3/day and presents values for children of various ages. These recommendations were derived from data presented in U.S. EPA (1989). The newer study by Layton (1993) was not considered. In addition, the Sourcebook presents probability distributions derived by Brorby and Finley (1993). For each distribution, the @Risk formula is provided for direct use in the @Risk simulation software (Palisade, 1992). The organization of this document makes it very convenient to use in support of Monte Carlo analysis. The reviews of the supporting studies are very brief with little analysis of their strengths and weaknesses. The Sourcebook has been classified as a relevant rather than key study because it is not the primary source for the data used to make recommendations in this document. The Sourcebook is very similar to this document in the sense that it summarizes exposure factor data and recommends values. As such, it is clearly relevant as an alternative information source on inhalation rates as well as other exposure factors.

5.2.4. Recommendations

In the Ozone Criteria Document prepared by the U.S. EPA Office of Environmental Criteria and Assessment, the EPA identified the collapsed range of activities and its corresponding VR as follows: light exercise (V_E < 23 L/min or 1.4 m^3/hr); moderate/ medium exercise (V_E= 24-43 L/min or 1.4-2.6 m^3/hr); heavy exercise (V_E= 43-63 L/min or 2.6-3.8 m^3/hr); and very heavy exercise (V_E> 64 L/min or 3.8 m^3/hr). (Adams, 1993).

Recent peer reviewed scientific papers and an EPA report comprise the studies that were evaluated in this Chapter. These studies were conducted in the United States among both men and women of different age groups. All are widely available. The confidence ratings in the inhalation rate recommendations are shown in Table 5-22.

Each study focused on ventilation rates and factors that may affect them. Studies were conducted among randomly selected volunteers. Efforts were made to include men, women, different age groups, and different kinds of activities. Measurement methods are indirect, but reproducible. Methods are well described (except for questionnaires) and experimental error is well

The overall mean predicted VR was 0.42 m^3/hr for sleep; 0.71 m^3/hr for slow activity; 0.84 m^3/hr for medium activity; and 2.63 m^3/hr for fast activity.

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) are presented in Table 5-20. 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 5-20 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 (Table 5-20).

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 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.

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 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

Table 5-20. 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/hr)[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 liters/minute were converted to m^3/hr.

[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)

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 (one 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 subject's 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-hr 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 x 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, 0.9, 1.68, and 4.02 m^3/hr 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 percent of the subject's time; slow activity 59 percent; medium activity 7 percent; and fast activity 1 percent. The diary data covered an average of 69 hours per subject (Shamoo et al., 1991). Table 5-19 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).

Table 5-19. Distribution Pattern of Predicted VR and EVR (equivalent ventilation rate) for 20 Outdoor Workers

Self-Reported Activity Level	N[c]	VR (m^3/hr)[a] Arithmetic Mean ± SD	VR (m^3/hr)[a] Geometric Mean ± SD	EVR[b] (m^3/hr/m^2 body surface) Arithmetic Mean ± SD	EVR[b] (m^3/hr/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 liters/minute were converted to m^3/hr.
[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

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/hr), medium (1.5-2.3 m^3/hr), heavy (2.4-3.8 m^3/hr), and very heavy (3.8 m^3/hr 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 two 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 19-50 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 one 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 percent 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 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 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).

A limitation associated with this study is 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.

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

Table 5-16. Summary of Human Inhalation Rates for Men, Women, and Children by Activity Level (m^3/hour)[a]

	n[b]	Resting[c]	n	Light[d]	n	Moderate[e]	n	Heavy[f]
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[g]		0.5		0.6		2.1		3.9
Child, age 6 years	8	0.4	16	0.8	4	2.0	5	2.3
Child, age 10 years	10	0.4	40	1.0	29	1.2	43	3.9

[a] Values of inhalation rates for males, females, and children (male and female) presented in this table represent the mean of values reported for each activity level in 1985. (See Appendix Table 5A-7 for a detailed listing of the data from U.S. EPA, 1985.)
[b] n = 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.
[g] Derived by taking the mean of the adult male and adult female values for each activity level.

Source: Adapted from U.S. EPA, 1985

Table 5-17. 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	0.098
	TOTAL	20.4
Outdoors	Resting	0.505
	Light	0.505
	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 5-18. Summary of Daily Inhalation Rates Grouped by Age and Activity level

Subject	Daily Inhalation Rate (m^3/day)[a] Resting	Light	Moderate	Heavy	Total Daily IR[b] (m^3/day)
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[c]	5.60	6.71	2.96	0.85	16
Child (age 6)	4.47	8.95	2.82	0.50	16.74
Child (age 10)	4.47	11.19	4.51	0.85	21.02

[a] Daily inhalation rate was calculated using the following equation

$$IR = \frac{1}{T}\sum_{i=1}^{k} IR_i t_i$$

IR_i = inhalation rate at i^{th} activity (Table 5-16)
t_i = hours spent per day during i^{th} activity (Table 5-19)
k = number of activity periods
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) daily inhalation rate

Source: Generated using the data from U.S. EPA (1985) as shown in Tables 5-16 and 5-17.

8 hours of rest and 16 hours of light activities. It was also assumed that 16 hours were divided evenly between occupational and nonoccupational activities. It was assumed that a day consisted of 14 hours resting and 10 hours light activity for an infant (1 yr). A newborn's daily activities consisted of 23 hours resting and 1 hour light activity. Table 5-15 presents the daily inhalation rates obtained for all ages/genders. 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.

Table 5-15 Daily Inhalation Rates Estimated From Daily Activities[a]

Subject	Inhalation Rate (IR) Resting (m^3/hr)	Light Activity (m^3/hr)	Daily Inhalation Rate (DIR)[b] (m^3/day)
Adult Man	0.45	1.2	22.8
Adult Woman	0.36	1.14	21.1
Child (10 yrs)	0.29	0.78	14.8
Infant (1 yr)	0.09	0.25	3.76
Newborn	0.03	0.09	0.78

[a] Assumptions made were based on 8 hours resting and 16 hours light activity for adults and children (10 yrs); 14 hours resting and 10 hours light activity for infants (1 yr); 23 hours resting and 1 hour light activity for newborns.

[b]
$$DIR = \frac{1}{T}\sum_{i=1}^{k} IR_i t_i$$

IR_i = Corresponding inhalation rate at i^{th} activity
t_i = Hours spent during the ith activity
k = Number of activity periods
T = Total time of the exposure period (i.e., a day)

Source: ICRP 1981

A limitation associated with this study is that the validity and accuracy of the inhalation rates data used in the compilation were not specified. This may introduce some degree of uncertainty in the results obtained. Also, the approach used involved assuming hours spent by various age/gender cohorts in specific activities. These assumptions may over/under-estimate the inhalation rates obtained.

U.S. EPA (1985) - Development of Statistical Distributions or Ranges of Standard Factors Used in Exposure Assessments - Due to a paucity of information in the literature regarding equations used to develop statistical distributions of minute ventilation/ventilation rate at all activity levels for male and female children and adults, the U.S. EPA (1985) compiled measured values of minute ventilation for various age/gender cohorts from early studies. In more recent investigations, minute ventilations have been measured more as background information than as research objective itself and the available studies have been for specific subpopulations such as obese, asthmatics, or marathon runners. The data compiled by the U.S. EPA (1985) for each age/gender cohorts were obtained at various activity levels. These levels were categorized as light, moderate, or heavy according to the criteria developed by the 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). The minute ventilation rates for adult males based on these activity level categories are detailed in Appendix Table 5A-6.

Table 5-16 presents a summary of inhalation rates by age, gender, and activity level (detailed data are presented in Appendix Table 5A-7). A description of activities included in each activity level is also presented in Table 5-16. Table 5-16 indicates that at rest, the average adult inhalation rate is 0.5 m^3/hr. The mean inhalation rate for children at rest, ages 6 and 10 years, is 0.4 m^3/hr. Table 5-17 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 transportation vehicle was 1.77. Based on the data presented in Tables 5-16 and 5-17, a daily inhalation rate was calculated for adults and children by using a time-activity-ventilation approach. These data are presented in Table 5-18. The calculated average daily inhalation rate is 16 m^3/day for adults. The average daily inhalation rate for children (6 and 10 yrs) is 18.9 m^3/day ([16.74 + 21.02]/2).

A limitation associated with this study is 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 subjects and the data are presented for both adults and children.

Shamoo et al. (1990) - Improved Quantitation of Air Pollution Dose Rates by Improved Estimation of Ventilation Rate- Shamoo et al. (1990) conducted this 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

5.3. REFERENCES FOR CHAPTER 5

Adams, W.C. (1993) Measurement of breathing rate and volume in routinely performed daily activities. Final Report. California Air Resources Board (CARB) Contract No. A033-205. June 1993. 185 pgs.

American Industrial Health Council (AIHC). (1994) Exposure factors sourcebook. AIHC, Washington, DC.

Basiotis, P.P.; Thomas, R.G.; Kelsay, J.L.; Mertz, W. (1989) Sources of variation in energy intake by men and women as determined from one year's daily dietary records. Am. J. Clin. Nutr. 50:448-453.

Benjamin, G.S. (1988) "The lungs." In: Fundamentals of Industrial Hygiene, Third Edition, Plog, B.A., ed. Chicago, IL: National Safety Council, p. 31-45.

Brorby, G.; Finley, B. (1993) Standard probability density functions for routine use in environmental health risk assessment. Presented at the Society of Risk Analysis Meeting, December 1993, Savannah, GA.

ICRP. (1981) International Commission on Radiological Protection. Report of the task group on reference man. New York: Pergammon Press.

Layton, D.W. (1993) Metabolically consistent breathing rates for use in dose assessments. Health Physics 64(1):23-36.

Linn, W.S.; Shamoo, D.A.; Hackney, J.D. (1992) Documentation of activity patterns in "high-risk" groups exposed to ozone in the Los Angeles area. In: Proceedings of the Second EPA/AWMA Conference on Tropospheric Ozone, Atlanta, Nov. 1991. pp. 701-712. Air and Waste Management Assoc., Pittsburgh, PA.

Linn, W.S.; Spier, C.E.; Hackney, J.D. (1993) Activity patterns in ozone-exposed construction workers. J. Occ. Med. Tox. 2(1):1-14.

Menzel, D.B.; Amdur, M.O. (1986) Toxic responses of the respiratory system. In: Klaassen, C.; Amdur, M.O.; Doull, J., eds. Toxicology, The Basic Science of Poisons. 3rd edition. New York: MacMillan Publishing Company.

Najjar, M.F.; Rowland, M. (1987) Anthropometric reference data and prevalence of overweight: United States. 1976-80. Hyattsville, MD: National Center for Health Statistics. U.S. Department of Health and Human Services: DHHS Publication No. (PHS)87-1688.

Palisade. (1992) @Risk User Guide. Newfield, NY: Palisade Corporation.

Sallis, J.F.; Haskell, W.L.; Wood, P.D.; Fortmann, S.P.; Rogers, T.; Blair, S.N.; Paffenbarger, Jr., R.S. (1985) Physical activity assessment methodology in the Five-City project. Am. J. Epidemiol. 121:91-106.

Shamoo, D.A.; Trim, S.C.; Little, D.E.; Linn, W.S.; Hackney, J.D. (1990) Improved quantitation of air pollution dose rates by improved estimation of ventilation rate. In: Total Exposure Assessment Methodology: A New Horizon, pp. 553-564. Air and Waste Management Assoc., Pittsburgh, PA.

Shamoo, D.A.; Johnson, T.R.; Trim, S.C.; Little, D.E.; Linn, W.S.; Hackney, J.D. (1991) Activity patterns in a panel of outdoor workers exposed to oxidant pollution. J. Expos. Anal. Environ. Epidem. 1(4):423-438.

Shamoo, D.A.; Trim, S.C.; Little, D.E.; Whynot, J.D.; Linn, W.S. (1992) Effectiveness of training subjects to estimate their level of ventilation. J. Occ. Med. Tox. 1(1):55-62.

Spier, C.E.; Little, D.E.; Trim, S.C.; Johnson, T.R.; Linn, W.S.; Hackney, J.D. (1992) Activity patterns in elementary and high school students exposed to oxidant pollution. J. Exp. Anal. Environ. Epid. 2(3):277-293.

U.S. EPA. (1985) Development of statistical distributions or ranges of standard factors used in exposure assessments. Washington, DC: Office of Health and Environmental Assessment; EPA report No. EPA 600/8-85-010. Available from: NTIS, Springfield, VA; PB85-242667.

U.S. EPA. (1989) Exposure factors handbook. Washington, DC: Office of Research and Development, Office of Health and Environmental Assessment. EPA/600/18-89/043.

U.S. EPA. (1992) Guidelines for exposure assessment. Washington, DC: Office of Research and Development, Office of Health and Environmental Assessments. EPA/600/Z-92/001.

U.S. EPA. (1994) Methods for derivation of inhalation reference concentrations and application of inhalation dosimetry. Washington, DC: Office of Health and Environmental Assessment. EPA/600/8-90/066F.

Table 5-25. Summary of Adult Inhalation Rates for Short-Term Exposure Studies

Arithmetic Mean (m^3/hr) Activity Level					
Rest	Sedentary	Light	Moderate	High	Reference
0.5	0.5	1.4	2.4	3.3	Adams, 1993 (Lab protocols)
--	0.6	1.2	1.8	--	Adams, 1993 (Field protocols)
0.4	0.4	0.7	1.4	3.6	Layton, 1993 (Short-term exposure)
0.4	--	0.6	1.5	3.0	Layton, 1993 (3rd approach)
--	--	1.0	1.6	3.0	Linn et al., 1992

Table 5-26. Summary of Children's (18 years old or less) Inhalation Rates for Long-Term Exposure Studies*

Arithmetic Mean (m^3/day)				
Age	Males	Females	Males and Females	Reference
less than 1 yr	--	--	4.5	Layton, 1993
1-2 years	--	--	6.8	Layton, 1993
3-5 years	--	--	8.3	Layton, 1993
6-8 years	--	--	10	Layton, 1993
9-11 years	14	13	--	Layton, 1993
12-14 years	15	12	--	Layton, 1993
15-18 years	17	12	--	Layton, 1993

* Layton, 1993 1st approach.

Table 5-27. Summary of Children's Inhalation Rates for Short-Term Exposure Studies

Arithmetic Mean (m^3/hr) Activity Level					
Rest	Sedentary	Light	Moderate	High	Reference
0.4	0.4	0.8	--	--	Adams, 1993 (Lab protocols)
--	--	--	0.9	--	Adams, 1993 (Field protocols)
0.2	0.3	0.5	1.0	2.5	Layton, 1993 (Short-term data)
--	--	1.8	2.0	2.2	Spier et al., 1992 (10-12 yrs)
--	--	0.8	1.0	11	Linn et al., 1992 (10-12 yrs)

Table 5-24 Summary of Inhalation Rate Studies

Study	Population Surveyed	Survey Time Period	Data Generated	Limitations/Advantages
KEY INHALATION RATE STUDIES:				
Adams, 1993	n = 160, ages 6-77, n = 40, ages 3-12	Three 25 min phases of resting protocol in the lab 6 mins of active protocols in the lab. 30 min phases of field protocols repeated once.	Mean values of IR for adult males and females and children by their activity levels	HR correlated poorly with IR
Layton, 1993	NFCS survey: n=30,000, NHANES survey: n=20,000 Time Activity survey: n=2,126		Daily IRs, IRs at 5 activity levels; and IR for short term exposures at 5 activity levels	Reported food biases in the dietary surveys employed, time activity survey was based on recall
Linn et al., 1992	Panel 1 - 20 healthy outdoor workers, ages 19-50, Panel 2 - 17 healthy elementary school students, ages 10-12, Panel 3 - 19 healthy high school students, ages 13-17, Panel 4 - 49 adult asthmatics, ages 18-50, Panel 5 - 24 adult asthmatics, ages 19-46, Panel 6 - 13 young asthmatics, ages 11-16, Panel 7 - 7 construction workers, ages 26-34	Late spring and early autumn 3 diary days. Construction workers' diary day.	Mean and upper estimates of IR, Mean IR at 3 activity levels	Small sample size, Calibration data not obtained over full HR range, activities based on short term diary data
Linn et al., 1993	n = 19 construction workers	(Mid July-early November, 1991) Diary recordings before work, during work and break times	Distribution patterns of hourly IR by activity level	Small sample population size, breathing rates subjective in nature, activities based on short term diary data
Spier et al., 1992	n = 36 students, ages 10-17.	(Late September - October) Involved 3 consecutive days of diary recording	Distribution patterns of hourly IR by activity levels and location	Activities based on short term diary data, self estimated breathing rate by younger population was biased, small sample population size
RELEVANT INHALATION RATE STUDIES:				
ICRP, 1974	Based on data from other references	--	Reference daily IR for adult females, adult males, children (10 yrs), and infant (1 yr)	Validity and accuracy of data set employed not defined, IR was estimated not measured
Shamoo et al., 1990	n = 9 volunteer workers ages 21-37, n = 20 outdoor workers, 19-50 years old	Involved 3 min indoor sessions/two 3 hr outdoor session at 4 activity levels	No IR data presented	No useful data were presented for dose assessments studies
Shamoo et al., 1991	n = 20 outdoor workers, ages 19-50	Diary recordings of three 24 hr. periods within a week	Distribution patterns of IR and EVR by activity levels and location	Small sample size, short term diary data
Shamoo et al., 1992	n = 9 non sedentary subjects, ages 21-37.	3 min intervals of indoor exercises/two 3 hr outdoor exercise sessions at 4 activity levels	Actual measured ventilation rates presented	Small sample size, training approach may not be cost effective, VR obtained for outdoor workers which are sensitive subpopulation
U.S. EPA, 1985	Based on data from several literature sources	--	Estimated IR for adult males, adult females and children (ages 6 and 10) by various activity levels	Validity and accuracy of data set employed not defined, IR was estimated not measured

Note: IR = inhalation rate; HR = heart rate, EVR = equivalent ventilation rate

Table 5-23 Summary of Recommended Values for Inhalation

Population	Mean	Upper Percentile
Long-term Exposures		
Infants		
<1 year	4.5 m^3/day	—
Children		
1-2 years	6.8 m^3/day	—
3-5 years	8.3 m^3/day	—
6-8 years	10 m^3/day	—
9-11 years		
males	14 m^3/day	—
females	13 m^3/day	—
12-14 years		
males	15 m^3/day	—
females	12 m^3/day	—
15-18 years		
males	17 m^3/day	—
females	12 m^3/day	—
Adults (19-65+ yrs)		
females	11.3 m^3/day	—
males	15.2 m^3/day	—
Short-term Exposures		
Adults		
Rest	0.4 m^3/hr	—
Sedentary Activities	0.5 m^3/hr	—
Light Activities	1.0 m^3/hr	—
Moderate Activities	1.6 m^3/hr	—
Heavy Activities	3.2 m^3/hr	—
Children		
Rest	0.3 m^3/hr	—
Sedentary Activities	0.4 m^3/hr	—
Light Activities	1.0 m^3/hr	—
Moderate Activities	1.2 m^3/hr	—
Heavy Activities	1.9 m^3/hr	—
Outdoor Workers		
Hourly Average	1.3 m^3/hr	3.3 m^3/hr
Slow Activities	1.1 m^3/hr	
Moderate Activities	1.5 m^3/hr	
Heavy Activities	2.5 m^3/hr	

Note: See Tables 5-25, 5-26, and 5-27 for [illegible]

which distribution of activity patterns are specified, the recommended average rates are 0.4 m^3/hr during rest; 0.5 m^3/hr for sedentary activities; 1.0 m^3/hr for light activities; 1.6 m^3/hr for moderate activities; and 3.2 m^3/hr for heavy activities.

Children (18 yrs old or less including infants) - For the purpose of this recommendation, children are defined as males and females between the ages of 1-18 years old, while infants are individuals less than 1 year old. The inhalation rates for children are presented below according to different exposure scenarios. The daily inhalation rates for long-term dose assessments, are based on the first approach of Layton (1993) (Table 5-11) and are summarized in Table 5-26.

Based on the key study results (i.e., Layton, 1993), the recommended daily inhalation rate for infants (children less than 1 yr), during long-term dose assessments is 4.5 m^3/day. For children 1-2 years old, 3-5 years old, and 6-8 years old, the recommended daily inhalation rates are 6.8 m^3/day, 8.3 m^3/day, and 10 m^3/day, respectively. Recommended values for children aged 9-11 years are 14 m^3/day for males and 13 m^3/day for females. For children aged 12-14 years and 15-18 years, the recommended values are shown in Table 5-23.

For short-term exposures for children aged 18 years and under, in which activity patterns are known, the data are summarized in Table 5-27. For short term exposures, the recommended average hourly inhalation rates are based on these key studies. They are averaged over each activity held as follows, 0.3 m^3/hr during rest; 0.4 m^3/hr for sedentary activities; 1.0 m^3/hr for light activities; 1.2 m^3/hr for moderate activities; and 1.9 m^3/hr for heavy activities. The recommended short-term exposure data also include infants (less than 1 yr). These values represent averages of the activity level data from key studies (Table 5-27).

Outdoor Worker - Inhalation rate data for outdoor workers/athlete are limited. However, based on the key studies (Linn et al., 1992 and 1993), the recommended average hourly inhalation rate for outdoor workers is 1.3 m^3/hr and the upper-percentile rate is 3.3 m^3/hr (see Tables 5-5 and 5-8). This is calculated as the weighted mean of the 99th percentile values reported for the individuals on Panels 1 and 7 in Tables 5-5 and the 19 subjects in Table 5-8. The recommended average inhalation rates for outdoor workers based on the activity levels categorized as slow (light activities), medium (moderate activities), and fast (heavy activities) are 1.1 m^3/hr, 1.5 m^3/hr, and 2.5 m^3/hr, respectively. These values are based on the data from Linn et al. (1992 and 1993) and are the weighted mean of the values for the individuals on Panels 1 and 7 in Table 5-5 and the 19 outdoor workers in Table 5-9. Inhalation rates may be higher among outdoor workers/athletes because levels of activity outdoors may be higher. Therefore, this subpopulation group may be more susceptible to air pollutants and are considered a "high-risk" subgroup (Shamoo et al., 1991; Linn et al., 1992).

Table 5-22 Confidence in Inhalation Rate Recommendations

Considerations	Rationale	Rating
Study Elements		
• Peer Review	Studies are from peer reviewed journal articles and an EPA peer reviewed report.	High
• Accessibility	Studies in journals have wide circulation. EPA reports are available from the National Technical Information Service.	High
• Reproducibility	Information on questionnaires and interviews were not provided.	Medium
• Focus on factor of interest	Studies focused on ventilation rates and factors influencing them.	High
• Data pertinent to U.S.	Studies conducted in the U.S.	High
• Primary data	Both data collection and re-analysis of existing data occurred.	Medium
• Currency	Recent studies were evaluated.	High
• Adequacy of data collection period	Effort was made to collect data over time.	High
• Validity of approach	Measurements were made by indirect methods.	Medium
• Representativeness of the population	An effort has been made to consider age and gender, but not systematically.	Medium
• Characterization of variability	An effort has been made to address age and gender, but not systematically.	High
• Lack of bias in study design	Subjects were selected randomly from volunteers and measured in the same way.	High
• Measurement error	Measurement error is well documented by statistics, but procedures measure factor indirectly.	Medium
Other Elements		
• Number of studies	Five key studies and six relevant studies were evaluated.	
• Agreement between researchers	There is general agreement among researchers using different experimental methods.	High
Overall Rating	Several studies exist that attempt to estimate inhalation rates according to age, gender and activity.	High

documented. There is general agreement with these estimates among researchers.

The recommended inhalation rates for adults, children, and outdoor workers/athletes are based on the key studies described in this chapter (Table 5-23). Different survey designs and populations were utilized in the studies described in this Chapter. A summary of these designs, data generated, and their limitations/advantages are presented in Table 5-24. Excluding the study by Layton (1993), the population surveyed in all of the key studies described in this report were limited to the Los Angeles area. This regional population may not represent the general U.S. population and may result in biases. However, based on other aspects of the study design, these studies were selected as the basis for recommended inhalation rates.

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. The recommended values for adults, children (including infants), and outdoor workers/athletes for use in various exposure scenarios are discussed below. These rates were calculated by averaging the inhalation rates for each activity level from the various key studies (see Table 5-25).

Adults (19-65+ yrs) - Adults in this recommendation include young to middle age adults (19-64 yrs), and older adults (65+ yrs). The daily average inhalation rates for long term exposure for adults are: 11.3 m^3/day for women and 15.2 m^3/day for men. These values are averages of the inhalation rates provided for males and females in each of the three approaches of Layton (1993) (Tables 5-11 through 5-14). An upper percentile is not recommended. Additional research and analysis of activity pattern data and dietary data in the future is necessary to attempt to calculate upper percentiles.

The recommended value for the general population average inhalation rate, 11.3 m^3/day for women and 15.2 m^3/day for men, is different than the 20 m^3/day which has commonly been assumed in past EPA risk assessments. In addition, recommendations are presented for various ages and special populations (athletes, outdoor workers) which also differ from 20 m^3/day. Assessors are encouraged to use values which most accurately reflect the exposed population.

For exposure scenarios where the distribution of activity patterns is known, the following results, calculated from the studies referenced are shown in Table 5-25. Based on these key studies, the following recommendations are made: for short term exposures in

combined with the total surface area of that body part. No reduction of body part area is made for clothing coverage using this approach. Thus, assessors who adopt this approach, should not use the defaults presented above for soil exposed skin area. Rather, they should use Table 6-4 to obtain total surface areas of specific body parts. See detailed discussion below.

6.3. SOIL ADHERENCE TO SKIN

6.3.1. Background

Soil adherence to the surface of the skin is a required parameter to calculate dermal dose when the exposure scenario involves dermal contact with a chemical in soil. A number of studies have attempted to determine the magnitude of dermal soil adherence. These studies are described in detail in U.S. EPA (1992b). This section summarizes recent studies that estimate soil adherence to skin for use as exposure factors.

6.3.2. Key Soil Adherence to Skin Studies

Kissel et al. (1996a) - Factors Affecting Soil Adherence to Skin in Hand-Press Trials: Investigation of Soil Contact and Skin Coverage - Kissel et al. (1996a) conducted soil adherence experiments using five soil types (descriptor) obtained locally in the Seattle, Washington, area: sand (211), loamy sand (CP), loamy sand (85), sandy loam (228), and silt loam (72). All soils were analyzed by hydrometer (settling velocity) to determine composition. Clay contents ranged from 0.5 to 7.0 percent. Organic carbon content, determined by combustion, ranged from 0.7 to 4.6 percent. Soils were dry sieved to obtain particle size ranges of <150, 150-250, and >250 μm. For each soil type, the amount of soil adhering to an adult female hand, using both sieved and unsieved soils, was determined by measuring the difference in soil sample weight before and after the hand was pressed into a pan containing the test soil. Loadings were estimated by dividing the recovered soil mass by total hand area, although loading occurred primarily on only one side of the hand. Results showed that generally, soil adherence to hands could be directly correlated with moisture content, inversely correlated with particle size, and independent of clay content or organic carbon content.

Kissel et al. (1996b) - Field Measurement of Dermal Soil Loading Attributable to Various Activities: Implications for Exposure Assessment - Further experiments were conducted by Kissel et al. (1996b) to estimate soil adherence associated with various indoor and outdoor activities: greenhouse gardening, tae kwon do karate, soccer, rugby, reed gathering, irrigation installation, truck farming, and playing in mud. A summary of field studies by activity, gender, age, field conditions, and clothing worn is presented in Table 6-11. Subjects' body surfaces (forearms, hands, lower legs in all cases, faces, and/or feet; pairs in some cases) were washed before and after monitored activities. Paired samples were pooled into single ones. Mass recovered was converted to loading using allometric models of surface area. These data are presented in Table 6-12. Results presented are based on direct measurement of soil loading on the surfaces of skin before and after occupational and recreational activities that may be expected to have soil contact (Kissel et al., 1996b).

6.3.3. Relevant Soil Adherence to Skin Studies

Lepow et al. (1975) - Investigations into Sources of Lead in the Environment of Urban Children - This study was conducted to identify the behavioral and environmental factors contributing to elevated lead levels in urban preschool children. The study was performed over 6 to 25 months. Samples of dirt from the hands of subjects were collected during the course of play around the areas where they lived. Preweighed self-adhesive labels were used to sample a standard area on the palm of the hands of 16 male and female children. The labels were pressed on a single area, often pressed several times, to obtain an adequate sample. In the laboratory, labels were equilibrated in a desiccant cabinet for 24 hours (comparable to the preweighed desiccation), then the total weight was recorded. The mean weight of dirt from the 22 hand sample labels was 11 mg. This corresponds to 0.51 mg/cm^2. Lepow et al. (1975) reported that this amount (11 mg) represented only a small fraction (percent not specified) of the total amount of surface dirt present on the hands, because much of the dirt may be trapped in skin folds and creases or there may be a patchy distribution of dirt on hands.

Roels et al. (1980) - Exposure to Lead by the Oral and the Pulmonary Routes of Children Living in the Vicinity of a Primary Lead Smelter - Roels et al. (1980) examined blood lead levels among 661 children, 9 to 14 years old, who lived in the vicinity of a large lead smelter in Brussels, Belgium. During five different study periods, lead levels were assessed by rinsing the childrens' hands in 500 mL dilute nitric acid. The amount of lead on the hands was divided by the concentration of lead in soil to

the particular body part(s). For example, to assess exposure to a chemical in a cleaning product for which only the hands are exposed, surface area values for hands from Table 6-4 can be used. For exposure to both hands and arms, mean surface areas for these parts from Table 6-4 may be summed to estimate the total surface area exposed. The mean surface area of these body parts for men and women is as follows:

	Surface Area (m^2)	
	Men	Women
Arms (includes upper arms and forearms)	0.228	0.210
Hands	0.084	0.075
Total area	0.312	0.285

Therefore, the total body part surface area that may be in contact with the chemical in the cleaning product in this example is 0.312 m^2 for men and 0.285 m^2 for women.

A common assumption is that clothing prevents dermal contact and subsequent absorption of contaminants. This assumption may be false in cases where the chemical may be able to penetrate clothing, such as in a fine dust or liquid suspension. Studies using personal patch monitors placed beneath clothing of pesticide workers exposed to fine mists and vapors show that a significant proportion of dermal exposure may occur at anatomical sites covered by clothing (U.S. EPA, 1992b). In addition, it has been demonstrated that a "pumping" effect can occur which causes material to move under loose clothing (U.S. EPA, 1992b). Furthermore, studies have demonstrated that hands cannot be considered to be protected from exposure even if waterproof gloves are worn (U.S. EPA, 1992b). This may be due to contamination to the interior surface of the gloves when donning or removing them during work activities (U.S. EPA, 1992b). Depending on the task, pesticide workers have been shown to experience 12 percent to 43 percent of their total exposure through their hands, approximately 20 percent to 23 percent through their heads and necks, and 36 percent to 64 percent through their torsos and arms, despite the use of protective gloves and clothing (U.S. EPA, 1992b).

For swimming and bathing scenarios, past exposure assessments have assumed that 75 percent to 100 percent of the skin surface is exposed (U.S. EPA, 1992b). As shown in Table 6-4, total adult body surface areas can vary from about 17,000 cm^2 to 23,000 cm^2. The mean is reported as approximately 20,000 cm^2.

For default purposes, adult body surface areas of 20,000 cm^2 (central estimate) to 23,000 cm^2 (upper percentile) are recommended in U.S. EPA (1992b). Tables 6-2 and 6-3 can also be used when the default values are not preferred. Central and upper-percentile values for children should be derived from Table 6-6 or 6-7.

Unlike exposure to liquids, clothing may or may not be effective in limiting the extent of exposure to soil. The 1989 Exposure Factors Handbook presented two adult clothing scenarios for outdoor activities (U.S. EPA, 1989):

> **Central tendency mid range:** Individual wears long sleeve shirt, pants, and shoes. The exposed skin surface is limited to the head and hands (2,000 cm^2).
>
> **Upper percentile:** Individual wears a short sleeve shirt, shorts, and shoes. The exposed skin surface is limited to the head, hands, forearms, and lower legs (5,300 cm^2).

The clothing scenarios presented above, suggest that roughly 10 percent to 25 percent of the skin area may be exposed to soil. Since some studies have suggested that exposure can occur under clothing, the upper end of this range was selected in *Dermal Exposure Assessment: Principles and Applications* (U.S. EPA, 1992b) for deriving defaults. Thus, taking 25 percent of the total body surface area results in defaults for adults of 5,000 cm^2 to 5,800 cm^2. These values were obtained from the body surface areas in Table 6-2 after rounding to 20,000 cm^2 and 23,000 cm^2, respectively. The range of defaults for children can be derived by multiplying the 50th and 95th percentiles by 0.25 for the ages of interest.

When addressing soil contact exposures, assessors may want to refine estimates of surface area exposed on the basis of seasonal conditions. For example, in moderate climates, it may be reasonable to assume that 5 percent of the skin is exposed during the winter, 10 percent during the spring and fall, and 25 percent during the summer.

The previous discussion, has presented information about the area of skin exposed to soil. These estimates of exposed skin area should be useful to assessors using the traditional approach of multiplying the soil adherence factor by exposed skin area to estimate the total amount of soil on skin. The next section presents soil adherence data specific to activity and body part and is designed to be

D'Agostino's test. The results indicate that the SA/BW ratios for infants are lognormally distributed and the SA/BW ratios for adults and all ages combined are normally distributed (Figure 6-2). SA/BW ratios for children were neither normally nor lognormally distributed. According to Phillips et al. (1993), SA/BW ratios should be used to calculate LADDs by replacing the body surface area factor in the numerator of the LADD equation with the SA/BW ratio and eliminating the body weight factor in the denominator of the LADD equation.

The effect of gender and age on SA/BW distribution was also analyzed by classifying the 401 observations by gender and age. Statistical analyses indicated no significant differences between SA/BW ratios for males and females. SA/BW ratios were found to decrease with increasing age.

6.2.4. Relevant Surface Area Studies

Murray and Burmaster (1992) - Estimated Distributions for Total Body Surface Area of Men and Women in the United States - In this study, distributions of total body surface area for men and women ages 18 to 74 years were estimated using Monte Carlo simulations based on height and weight distribution data. Four different formulae for estimating body surface area as a function of height and weight were employed: Dubois and Dubois (1916); Boyd (1935); U.S. EPA (1985); and Costeff (1966). The formulae of Dubois and Dubois (1916); Boyd (1935); and U.S. EPA (1985) are based on height and weight. They are discussed in Appendix 6A. The formula developed by Costeff (1966) is based on 220 observations that estimate body surface area based on weight only. This formula is:

$$SA = 4W + 7/W + 90 \qquad \text{(Eqn. 6-2)}$$

where:

SA = Surface Area (m^2); and
W = Weight (kg).

Formulae were compared and the effect of the correlation between height and weight on the body surface area distribution was analyzed.

Monte Carlo simulations were conducted to estimate body surface area distributions. They were based on the bivariate distributions estimated by Brainard and Burmaster (1992) for height and natural logarithm of weight and the formulae described above. A total of 5,000 random samples each for men and women were selected from the two correlated bivariate distributions. Body surface area calculations were made for each sample, and for each formula, resulting in body surface area distributions. Murray and Burmaster (1992), found that the body surface area frequency distributions were similar for the four models (Table 6-10). Using the U.S. EPA (1985) formula, the median surface area values were calculated to be 1.96 m^2 for men and 1.69 m^2 for women. The median value for women is identical to that generated by U.S. EPA (1985) but differs for men by approximately 1 percent. Body surface area was found to have lognormal distributions for both men and women (Figure 6-3). It was also found that assuming correlation between height and weight influences the final distribution by less than 1 percent.

AIHC (1994) - Exposure Factors Sourcebook - The Exposure Factors Sourcebook (AIHC, 1994) provides similar body surface area data as presented here. Consistent with this document, average and percentile values are presented on the basis of age and gender. In addition, the Sourcebook presents point estimates of exposed skin surface areas for various scenarios on the basis of several published studies. Finally, the Sourcebook presents probability distributions based on U.S. EPA (1989) and as derived by Thompson and Burmaster (1991); Versar (1991); and Brorby and Finley (1993). For each distribution, the @Risk formula is provided for direct use in the @Risk simulation software (Palisade, 1992). The organization of this document, makes it very convenient to use in support of Monte Carlo analysis. The reviews of the supporting studies are very brief with little analysis of their strengths and weaknesses. The Sourcebook has been classified as a relevant rather than key study because it is not the primary source for the data used to make recommendations in this document. The Sourcebook is very similar to this document in the sense that it summarizes exposure factor data and recommends values. As such, it is clearly relevant as an alternative information source on body surface area as well as other exposure factors.

6.2.5. Application of Body Surface Area Data

In many settings, it is likely that only certain parts of the body are exposed. All body parts that come in contact with a chemical must be considered to estimate the total surface area of the body exposed. The data in Table 6-4 may be used to estimate the total surface area of

Boyd (1935) that were complete for surface area, height, weight, and age for their analysis. Boyd (1935) had reported surface area estimates for 1,114 individuals using coating, triangulation, or surface integration methods (U.S. EPA, 1985).

U.S. EPA (1985) used SPS to generate equations to calculate surface area as a function of height and weight. These equations were then used to calculate body surface area distributions of the U.S. population using the height and weight data obtained from the National Health and Nutrition Examination Survey (NHANES) II and the computer program QNTLS of Rochon and Kalsbeck (1983).

The equation proposed by Gehan and George (1970) was determined by U.S. EPA (1985) to be the best choice for estimating total body surface area. However, the paper by Gehan and George (1970) gave insufficient information to estimate the standard error about the regression. Therefore, U.S. EPA (1985) used the 401 direct measurements of children and adults and reanalyzed the data using the formula of Dubois and Dubois (1916) and SPS to obtain the standard error (U.S. EPA, 1985).

Regression equations were developed for specific body parts using the Dubois and Dubois (1916) formula and using the surface area of various body parts provided by Boyd (1935) and Van Graan (1969) in conjunction with SPS. Regression equations for adults were developed for the head, trunk (including the neck), upper extremities (arms and hands, upper arms, and forearms) and lower extremities (legs and feet, thighs, and lower legs) (U.S. EPA, 1985). Table 6-1 presents a summary of the equation parameters developed by U.S. EPA (1985) for calculating surface area of adult body parts. Equations to estimate the body part surface area of children were not developed because of insufficient data.

Percentile estimates of total surface area and surface area of body parts developed by U.S. EPA (1985) using the regression equations and NHANES II height and weight data are presented in Tables 6-2 and 6-3 for adult males and adult females, respectively. The calculated mean surface areas of body parts for men and women are presented in Table 6-4. The standard deviation, the minimum value, and the maximum value for each body part are included. The median total body surface area for men and women and the corresponding standard errors about the regressions are also given. It has been assumed that errors associated with height and weight are negligible (U.S. EPA, 1985). The data in Table 6-5 present the percentage of total body surface by body part for men and women.

Percentile estimates for total surface area of male and female children presented in Tables 6-6 and 6-7 were calculated using the total surface area regression equation, NHANES II height and weight data, and using QNTLS. Estimates are not included for children younger than 2 years old because NHANES height data are not available for this age group. For children, the error associated with height and weight cannot be assumed to be zero because of their relatively small sizes. Therefore, the standard errors of the percentile estimates cannot be estimated, since it cannot be assumed that the errors associated with the exogenous variables (height and weight) are independent of that associated with the model; there are insufficient data to determine the relationship between these errors.

Measurements of the surface area of children's body parts are summarized as a percentage of total surface area in Table 6-8. Because of the small sample size, the data cannot be assumed to represent the average percentage of surface area by body part for all children. Note that the percent of total body surface area contributed by the head decreases from childhood to adult, while the percent contributed by the leg increases.

Phillips et al. (1993) - Distributions of Total Skin Surface Area to Body Weight Ratios - Phillips et al. (1993) observed a strong correlation (0.986) between body surface area and body weight and studied the effect of using these factors as independent variables in the LADD equation. Phillips et al. (1993) concluded that, because of the correlation between these two variables, the use of body surface area to body weight (SA/BW) ratios in human exposure assessments is more appropriate than treating these factors as independent variables. Direct measurement (coating, triangulation, and surface integration) data from the scientific literature were used to calculate body surface area to body weight (SA/BW) ratios for three age groups (infants aged 0 to 2 years, children aged 2.1 to 17.9 years, and adults 18 years and older). These ratios were calculated by dividing body surface areas by corresponding body weights for the 401 individuals analyzed by Gehan and George (1970) and summarized by U.S. EPA (1985). Distributions of SA/BW ratios were developed and summary statistics were calculated for each of the three age groups and the combined data set. Summary statistics for these populations are presented in Table 6-9. The shapes of these SA/BW distributions were determined using

values can be found in Section 5.3.1 of "Dermal Exposure Assessment: Principles and Applications" (U.S. EPA, 1992b).

For dermal contact with contaminated soil, estimation of the DA_{event} is different from the estimation for dermal contact with chemicals in water. It is based on the concentration of the chemical in soil, the adherence factor of soil to skin, and the absorption fraction. Information for DA_{event} estimation from soil contact can be found in U.S. EPA (1992b), Section 6.4.

The apparent simplicity of the absorption fraction (percent absorbed) makes this approach appealing. However, it is not practical to apply it to water contact scenarios, such as swimming, because of the difficulty in estimating the total material contacted (U.S. EPA, 1992b). It is assumed that there is essentially an infinite amount of material available, and that the chemical will be replaced continuously, thereby increasing the amount of material (containing the chemical) available by some large unknown amount. Therefore, the permeability coefficient -based approach is recommended over the absorption fraction approach for determining the dermally absorbed dose of chemicals in aqueous media.

Before the absorption fraction approach can be used in soil contact scenarios, the contaminant concentration in soil must be established. Not all of the chemical in a layer of dirt applied to skin may be bioavailable, nor is it assumed to be an internal dose. Because of the lack of K_p data for compounds bound to soil, and reduced uncertainty in defining an applied dose, the absorption fraction-based approach is suggested for determining the internal dose of chemicals in soil. More detailed explanation of the equations, assumptions, and approaches can be found in "Dermal Exposure Assessment: Principles and Applications" (U.S. EPA, 1992b).

6.2. SURFACE AREA

6.2.1. Background

The total surface area of skin exposed to a contaminant must be determined using measurement or estimation techniques before conducting a dermal exposure assessment. Depending on the exposure scenario, estimation of the surface area for the total body or a specific body part can be used to calculate the contact rate for the pollutant. This section presents estimates for total body surface area and for body parts and presents information on the application of body surface area data.

6.2.2. Measurement Techniques

Coating, triangulation, and surface integration are direct measurement techniques that have been used to measure total body surface area and the surface area of specific body parts. Consideration has been given for differences due to age, gender, and race. The results of the various techniques have been summarized in "Development of Statistical Distributions or Ranges of Standard Factors Used in Exposure Assessments" (U.S. EPA, 1985). The coating method consists of coating either the whole body or specific body regions with a substance of known or measured area. Triangulation consists of marking the area of the body into geometric figures, then calculating the figure areas from their linear dimensions. Surface integration is performed by using a planimeter and adding the areas.

The triangulation measurement technique developed by Boyd (1935) has been found to be highly reliable. It estimates the surface area of the body using geometric approximations that assume parts of the body resemble geometric solids (Boyd, 1935). More recently, Popendorf and Leffingwell (1976), and Haycock et al. (1978) have developed similar geometric methods that assume body parts correspond to geometric solids, such as the sphere and cylinder. A linear method proposed by DuBois and DuBois (1916) is based on the principle that the surface areas of the parts of the body are proportional, rather than equal to the surface area of the solids they resemble.

In addition to direct measurement techniques, several formulae have been proposed to estimate body surface area from measurements of other major body dimensions (i.e., height and weight) (U.S. EPA, 1985). Generally, the formulae are based on the principles that body density and shape are roughly the same and that the relationship of surface area to any dimension may be represented by the curve of central tendency of their plotted values or by the algebraic expression for the curve. A discussion and comparison of formulae to determine total body surface area are presented in Appendix 6A.

6.2.3. Key Body Surface Area Studies

U.S. EPA (1985) - Development of Statistical Distributions or Ranges of Standard Factors Used in Exposure Assessments - U.S. EPA (1985) analyzed the direct surface area measurement data of Gehan and George (1970) using the Statistical Processing System (SPS) software package of Buhyoff et al. (1982). Gehan and George (1970) selected 401 measurements made by

6. DERMAL ROUTE

Dermal exposure can occur during a variety of activities in different environmental media and microenvironments (U.S. EPA, 1992). These include:

- Water (e.g., bathing, washing, swimming);
- Soil (e.g., outdoor recreation, gardening, construction);
- Sediment (e.g., wading, fishing);
- Liquids (e.g., use of commercial products);
- Vapors/fumes (e.g., use of commercial products); and
- Indoors (e.g., carpets, floors, countertops).

The major factors that must be considered when estimating dermal exposure are: the chemical concentration in contact with the skin, the potential dose, the extent of skin surface area exposed, the duration of exposure, the absorption of the chemical through the skin, the internal dose, and the amount of chemical that can be delivered to a target organ (i.e., biologically effective dose) (see Figure 6-1). A detailed discussion of these factors can be found in Guidelines for Exposure Assessment (U.S. EPA, 1992a).

This chapter focuses on measurements of body surface areas and various factors needed to estimate dermal exposure to chemicals in water and soil. Information concerning dermal exposure to pollutants in indoor environments is limited. Useful information concerning estimates of body surface area can be found in "Development of Statistical Distributions or Ranges of Standard Factors Used in Exposure Assessments" (U.S. EPA, 1985). "Dermal Exposure Assessment: Principles and Applications (U.S. EPA, 1992b), provides detailed information concerning dermal exposure using a stepwise guide in the exposure assessment process.

The available studies have been classified as either key or relevant based on their applicability to exposure assessment needs and are summarized in this chapter. Recommended values are based on the results of the key studies. Relevant studies are presented to provide an added perspective on the state-of-knowledge pertaining to dermal exposure factors. All tables and figures presenting data from these studies are shown at the end of this chapter.

6.1. EQUATION FOR DERMAL DOSE

The average daily dose (ADD) is the dose rate averaged over a pathway-specific period of exposure expressed as a daily dose on a per-unit-body-weight basis. The ADD is used for exposure to chemicals with non-carcinogenic non-chronic effects. For compounds with carcinogenic or chronic effects, the lifetime average daily dose (LADD) is used. The LADD is the dose rate averaged over a lifetime.

For dermal contact with chemicals in soil or water, dermally absorbed average daily dose can be estimated by (U.S. EPA, 1992b):

$$ADD = \frac{DA_{event} \times EV \times ED \times EF \times SA}{BW \times AT} \qquad \text{(Eqn. 6-1)}$$

where:

ADD	=	average daily dose (mg/kg-day);
DA_{event}	=	absorbed dose per event (mg/cm^2-event);
EV	=	event frequency (events/day);
ED	=	exposure duration (years);
EF	=	exposure frequency (days/year);
SA	=	skin surface area available for contact (cm^2);
BW	=	body weight (kg); and
AT	=	averaging time (days) for noncarcinogenic effects, AT = ED and for carcinogenic effects, AT = 70 years or 25,550 days.

This method is to be used to calculate the absorbed dose of a chemical. Total body surface area (SA) is assumed to be exposed for a period of time (ED).

For dermal contact with water, the DA_{event} is estimated with consideration for the permeability coefficient from water, the chemical concentration in water, and the event duration. The approach to estimate DA_{event} is different for inorganic and organic compounds. The nonsteady-state approach to estimate the dermally absorbed dose from water is recommended as the preferred approach for organics which exhibit octanol-water partitioning (U.S. EPA, 1992b). First, this approach more accurately reflects normal human exposure conditions since the short contact times associated with bathing and swimming generally mean that steady state will not occur. Second, the approach accounts for uptake that can occur after the actual exposure event due to absorption of residual chemical trapped in skin tissue. Use of the nonsteady-state model for organics has implications for selecting permeability coefficient (K_p) values (U.S. EPA, 1992b). It is recommended that the traditional steady-state approach be applied to inorganics (U.S. EPA, 1992b). Detailed information concerning how to estimate absorbed dose per event (DA_{event}) and K_p

Table 5A-7 Minute Ventilation Ranges by Age, Sex, and Activity Level

Age	Sex	Ventilation ranges (liters/minute)											
		Resting			Light			Moderate			Heavy		
(years)		n	Range	Mean	n	Range	Mean	n	Range	Mean	n	Range	Mean
Infants	M F	316	0.25 - 2.09	0.84					---			---	
2	F		---			---			---			---	
	M		---			---			---			---	
3	F		---			---			---			---	
	M		---			---			---			---	
4	F		---			---			---		2	32.0 - 32.5	32.3
	M		---			---			---		4	39.3 - 43.3	41.2
5	F		---			---			---		3	31.0 - 35.0	32.8
	M		---			---			---		3	30.9 - 42.6	37.5
6	F		---			---			---		2	35.9 - 38.9	37.4
	M	8	5.0 - 7.0	6.5	16	5.0 - 32.0	13.9	4	28.0 - 43.0	33.3	3	35.5 - 43.5	40.3
7	F		---			---			---		3	48.2 - 51.4	49.6
	M		---			---			---		2	44.1 - 55.8	50.0
8	F		---			---			---		4	51.2 - 67.6	57.6
	M		---			---			---		3	59.3 - 62.2	60.7
9	F		---			---			---		27	55.8 - 63.4	50.9
	M		---			---			---		7	59.5 - 75.2	65.7
10	F		---			---			---		21	46.2 - 71.1	60.4
	M	10	5.2 - 8.3	7.1	20	5.2 - 35.0	17.2	9	41.0 - 68.0	53.4	6	63.9 - 74.6	70.5
	F		---			---			---		7	49.7 - 80.9	63.5
	M		---		20	---	20.3	20	---	33.1	9	47.6 - 77.5	65.5
12	F	54	4.1 - 16.1	15.4		---		4	19.6 - 45.3	26.5	31	65.5 - 79.9	71.8
	M	56	7.2 - 16.3	15.4		---		6	18.5 - 45.3	34.1	9	58.1 - 84.7	67.7
13	F	5	7.2 - 15.4	9.9		---		5	18.5 - 46.3	30.3	7	67.6 - 102.6	87.7
	M	16	3.1 - 15.4	8.9	30	3.1 - 24.9	16.4	29	14.4 - 48.4	32.8	38	27.8 - 105.0	57.9
14	F	53	3.1 - 15.6	14.9		---		3	21.6 - 37.1	28.1	5	80.7 - 100.7	88.9
	M	77	3.4 - 27.8	14.2		---		24	24.7 - 55.0	39.7	16	42.2 - 121.0	86.9
15	F	1	--	6.2		---		1	---	26.8	6	68.4 - 97.1	87.1
	M	8	3.1 - 26.8	11.1		---		7	27.8 - 46.3	39.3	6	45.4 - 140.3	110.5
16	F	50	---	15.2		---	---		---		8	73.6 - 119.1	93.9
	M	50	---	15.6		---			---		3	79.6 - 132.2	102.5
17	F		---			---			---		2	91.9 - 95.3	93.6
	M	12	5.8 - 9.0	7.3		---		12	40.0 - 63.0	45.6	3	83.4 - 137.3	107.7
18	F		---			---			---			---	
	M		---			---			---		9	99.7 - 143.0	120.9
Adults	F	595	4.2 - 41.66	5.3	786	4.2 - 29.4	8.3	196	20.7 - 34.2	26.5	211	23.4 - 114.8	47.9
Adults	M	454	2.3 - 18.8	12.2	102	2.3 - 27.6	13.8	102	14.4 - 78.0	43.9	267	38.6 - 133.4	80.0

n = number of observations

Note: Values in liters/minute can be converted to units of m³/hr by multiplying by the conversion factor, $\frac{60 \text{ minutes/hour}}{1000 \text{ liters/m}^3}$

Source: Adapted from U.S. EPA, 1985

Table 5A-6. Estimated Minute Ventilation Associated with Activity Level for Average Male Adult[a]

Level of work	L/min	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 5A-5. Selected Ventilation Values During Different Activity Levels Obtained From Various Literature Sources

Col.	1	2	3			4			5			6		
			Resting			Light Activity			Heavy Work			Maximal Work During Exercise		
Line	Subject	W (kg)	f	VT	V̇ᵉ	f	VT	V̇ᵉ	f	VT	V̇ᵉ	f	VT	V̇ᵉ
	Adult													
1	Man	68.5	12	750	7.4	17	1670	29	21	2030	43			
2	1.7 m² SA		12	500	6									
3	30y; 170 cm L		15	500	7.5	16	1250	20						
4	20-33 y	70.4										40	3050	111
5	Woman	54	12	340	4.5	19	860	16	30	880	25			
6	30 y; 160 cm L		15	400	6	20	940	19						
7	20-25 y; 165.8 cm L	60.3										46	2100	90
8	Pregnant (8th mo)		16	650	10									
	Adolescent													
9	male, 14-16 y		16	330	5.2							53	2520	113
10	male, 14-15 y	59.4												
11	female, 14-16 y		15	300	4.5									
12	female, 14-15 y; 164.9 cm L	56										52	1870	88
	Children													
13	10 y; 140 cm L		16	300	4.8	24	600	14						
14	males, 10-11 y	36.5										58	1330	71
15	males, 10-11 y; 140.6 cm L	32.5										61	1050	61
16	females, 4-6 y	20.8										70	600	40
17	females, 4-6 y; 111.6 cm L	18.4										66	520	34
18	Infant, 1 y		30	48	1.4[a]									
19	Newborn	2.5	34	15	0.5									
20	20 hrs-13 wk	2.5-5.3										68[b]	51[a,b]	3.5[b]
21	9.6 hrs	3.6	25	21	0.5									
22	6.6 days	3.7	29	21	0.6									

W = body weights referable to the dimension quoted in column 1; f = frequency (breaths/min); VT = tidal volume (ml); V̇ᵉ = minute volume (l/min); SA = surface area; cm L = length/height; y = years of age; wk = week.

[a] Calculated from V̇ᵉ = f x VT.
[b] Crying.

Source: ICRP, 1981.

Table 5A-3. Characteristics of Individual Subjects, Anthropometric Data, Job Categories, Calibration Results

Subj. #	Age (years)	Ht (in.)	Wt (lb.)	Ethnic Group[a]	Job[b]	Site[c]	Calibration HR Range[d]	Calibration r^2[e]
1761	26	71	180	Wht	GCW	Ofc	69-108	.91
1763	29	63	135	Asn	GCW	Ofc	80-112	.95
1764	32	71	165	Blk	Car	Ofc	56-87	.95
1765	30	73	145	Wht	GCW	Ofc	66-126	.97
1766	31	67	170	His	Car	Ofc	75-112	.89
1767	34	74	220	Wht	Car	Ofc	59-114	.98
1768	32	69	155	Blk	GCW	Ofc	62-152	.95
1769	32	77	230	Wht	Car	Hosp	69-132	.99
1770	26	70	180	Wht	Car	Hosp	63-106	.89
1771	39	66	150	Wht	Car	Hosp	88-118	.91
1772	32	71	260	Wht	Car	Hosp	83-130	.97
1773	39	69	170	Wht	Irn	Hosp	77-128	.95
1774	23	68	150	His	Car	Hosp	68-139	.98
1775	42	67	150	Wht	Irn	Hosp	76-118	.88
1776	29	70	180	His	Car	Hosp	68-152	.99
1778	35	76	220	Ind	Car	Hosp	70-129	.94
1779	40	70	175	Wht	Car	Hosp	72-140	.99
1780	37	75	242	His	Irn	Hosp	68-120	.98
1781	38	65	165	His	Lab	Hosp	66-121	.89
Mean	33	70	181				70-123	.94
SD	5	4	36				8-16	.04

[a] Abbreviations are interpreted as follows. Ethnic Group: Asn = Asian-Pacific, Blk = Black, His = Hispanic, Ind = American Indian, Wht = White

[b] Job: Car = carpenter, GCW = general construction worker, Irn = ironworker, Lab = laborer

[c] Site: Hosp = hospital building, Ofc = medical office complex. Calibration data

[d] HR range = range of heart rates in calibration study

[e] r^2 = coefficient of determination (proportion of ventilation rate variability explainable by heart rate variability under calibration-study conditions, using quadratic prediction equation).

Source: Linn et al. 1993

Table 5A-4. Statistics of the Age/Gender Cohorts Used to Develop Regression Equations for Predicting Basal Metabolic Rates (BMR)

Gender/Age (y)	BMR MJ d[-1]	±SD	CV[a]	Body Weight (kg)	N[b]	BMR Equation[c]	r[d]
Males							
Under 3	1.51	0.918	0.61	6.6	162	0.249 bw - 0.127	0.95
3 to < 10	4.14	0.498	0.12	21	338	0.095 bw + 2.110	0.83
10 to < 18	5.86	1.171	0.20	42	734	0.074 bw + 2.754	0.93
18 to < 30	6.87	0.843	0.12	63	2879	0.063 bw + 2.896	0.65
30 to < 60	6.75	0.872	0.13	64	646	0.048 bw + 3.653	0.6
60 +	5.59	0.928	0.17	62	50	0.049 bw + 2.459	0.71
Females							
Under 3	1.54	0.915	0.59	6.9	137	0.244 bw - 0.130	0.96
3 to < 10	3.85	0.493	0.13	21	413	0.085 bw + 2.033	0.81
10 to < 18	5.04	0.780	0.15	38	575	0.056 bw + 2.898	0.8
18 to < 30	5.33	0.721	0.14	53	829	0.062 bw + 2.036	0.73
30 to < 60	5.62	0.630	0.11	61	372	0.034 bw + 3.538	0.68
60 +	4.85	0.605	0.12	56	38	0.038 bw + 2.755	0.68

[a] Coefficient of variation (SD/mean)

[b] N = number of subjects

[c] Body weight (bw) in kg

[d] coefficient of correlation

Source: Layton, 1993

Table 5A-1. Mean Minute Ventilation (V_E, L/min) by Group and Activity for Laboratory Protocols

Activity		Young Children[a]	Children	Adult Females	Adult Males
Lying		6.19	7.51	7.12	8.93
Sitting		6.48	7.28	7.72	9.30
Standing		6.76	8.49	8.36	10.65
Walking	1.5 mph	10.25	DNP	DNP	DNP
	1.875 mph	10.53	DNP	DNP	DNP
	2.0 mph	DNP	14.13	DNP	DNP
	2.25 mph	11.68	DNP	DNP	DNP
	2.5 mph	DNP	15.58	20.32	24.13
	3.0 mph	DNP	17.79	24.20	DNP
	3.3 mph	DNP	DNP	DNP	27.90
	4.0 mph	DNP	DNP	DNP	36.53
Running	3.5 mph	DNP	26.77	DNP	DNP
	4.0 mph	DNP	31.35	46.03[b]	DNP
	4.5 mph	DNP	37.22	47.86[b]	57.30
	5.0 mph	DNP	DNP	50.78[b]	58.45
	6.0 mph	DNP	DNP	DNP	65.66[b]

[a] Young Children, male and female 3-5.9 yr olds; Children, male and female 6-12.9 yr 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 5A-2. Mean Minute Ventilation (V_E, L/min) by Group and Activity for Field Protocols

Activity	Young Children[a]	Children	Adult Females	Adult Males
Play	11.31	17.89	DNP	DNP
Car Driving	DNP	DNP	8.95	10.79
Car Riding	DNP	DNP	8.19	9.83
Yardwork	DNP	DNP	19.23[c]	26.07[b]/31.89[c]
Housework	DNP	DNP	17.38	DNP
Car Maintenance	DNP	DNP	DNP	23.21[d]
Mowing	DNP	DNP	DNP	36.55[e]
Woodworking	DNP	DNP	DNP	24.42[e]

[a] Young Children, male and female 3-5.9 yr olds; Children, male and female 6-12.9 yr 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] Mean value for young to middle-aged adults only

[c] Mean value for older adults only

[d] Older adults not included in the mean value since they did not perform this activity.

[e] Adolescents not included in mean value since they did not perform this activity

Source: Adams, 1993

APPENDIX 5A

VENTILATION DATA

Table 6.8 Percentage of Total Body Surface Area by Body Part for Children

Age (yr)	N M/F	Percent of Total											
		Head		Trunk		Arms		Hands		Legs		Feet	
		Mean	Min Max	Mean	Min Max	Mean	Min Max	Mean	Min Max	Mean	Min Max	Mean	Min Max
< 1	2 0	18 2	18 2-18 3	35 7	34 8-36 6	13 7	12 4-15 1	5 3	5 21-5 39	20 6	18 2-22 9	6 54	6 49 6 59
1 < 2	1 1	16 5	16 5 16 5	35 5	34 5-36 6	13 0	12 8 13 1	5 68	5 57-5 78	23 1	22 1-24 0	6 27	5 84 6 70
2 < 3	1 0	14 2		35 5		11 8		5 30		23 2		7 07	
3 < 4	0 5	13 6	13 3 14 0	31 9	29 9 32 8	14 4	14 2-14 7	6 07	5 83 6 32	26 8	26 0 28 6	7 21	6 80-7 88
4 < 5	1 3	13 8	12 1-15 3	31 5	30 5-32 4	14 0	13 0 15 5	5 70	5 15 6 62	27 8	26 0 29 3	7 29	6 91-8.10
5 < 6													
6 < 7	1 0	13 1		35 1		13 1		4 71		27 1		6 90	
7 < 8													
8 < 9													
9 < 10	0 2	12 0	11 6-12 5	34 2	33 4-34 9	12 3	11.7-12 8	5 30	5 15-5 44	28 7	28 5 28 8	7.58	7.38 7.77
10 < 11													
11 < 12													
12 < 13	1 0	8 74		34 7		13 7		5 39		30 5		7 03	
13 < 14	1 0	9 97		32 7		12 1		5 11		32 0		8 02	
14 < 15													
15 < 16													
16 < 17	1 0	7.96		32 7		13 1		5 68		33 6		6 93	
17 < 18	1 0	7.58		31 7		17 5		5 13		30 8		7 28	

N Number of subjects, male to female ratios

Source U S EPA 1985

Table 6-6. Total Body Surface Area of Male Children in Square Meters[a]

Age (yr)[b]	Percentile								
	5	10	15	25	50	75	85	90	95
2<3	0.527	0.544	0.552	0.569	0.603	0.629	0.643	0.661	0.682
3<4	0.585	0.606	0.620	0.636	0.664	0.700	0.719	0.729	0.764
4<5	0.633	0.658	0.673	0.689	0.731	0.771	0.796	0.809	0.845
5<6	0.692	0.721	0.732	0.746	0.793	0.840	0.864	0.895	0.918
6<7	0.757	0.788	0.809	0.821	0.866	0.915	0.957	1.01	1.06
7<8	0.794	0.832	0.848	0.877	0.936	0.993	1.01	1.06	1.11
8<9	0.836	0.897	0.914	0.932	1.00	1.06	1.12	1.17	1.24
9<10	0.932	0.966	0.988	1.00	1.07	1.13	1.16	1.25	1.29
10<11	1.01	1.04	1.06	1.10	1.18	1.28	1.35	1.40	1.48
11<12	1.00	1.06	1.12	1.16	1.23	1.40	1.47	1.53	1.60
12<13	1.11	1.13	1.20	1.25	1.34	1.47	1.52	1.62	1.76
13<14	1.20	1.24	1.27	1.30	1.47	1.62	1.67	1.75	1.81
14<15	1.33	1.39	1.45	1.51	1.61	1.73	1.78	1.84	1.91
15<16	1.45	1.49	1.52	1.60	1.70	1.79	1.84	1.90	2.02
16<17	1.55	1.59	1.61	1.66	1.76	1.87	1.98	2.03	2.16
17<18	1.54	1.56	1.62	1.69	1.80	1.91	1.96	2.03	2.09
3<6	0.616	0.636	0.649	0.673	0.728	0.785	0.817	0.842	0.876
6<9	0.787	0.814	0.834	0.866	0.931	1.01	1.05	1.09	1.14
9<12	0.972	1.00	1.02	1.07	1.16	1.28	1.36	1.42	1.52
12<15	1.19	1.24	1.27	1.32	1.49	1.64	1.73	1.77	1.85
15<18	1.50	1.55	1.59	1.65	1.75	1.86	1.94	2.01	2.11

[a] Lack of height measurements for children <2 years in NHANES II precluded calculation of surface areas for this age group.
[b] Estimated values calculated using NHANES II data.
Source: U.S. EPA, 1985

Table 6-7. Total Body Surface Area of Female Children in Square Meters[a]

Age (yr)[b]	Percentile								
	5	10	15	25	50	75	85	90	95
2<3	0.516	0.532	0.544	0.557	0.579	0.610	0.623	0.637	0.653
3<4	0.555	0.570	0.589	0.607	0.649	0.688	0.707	0.721	0.737
4<5	0.627	0.639	0.649	0.666	0.706	0.758	0.777	0.794	0.820
5<6	0.675	0.700	0.714	0.735	0.779	0.830	0.870	0.902	0.952
6<7	0.723	0.748	0.770	0.791	0.843	0.914	0.961	0.989	1.03
7<8	0.792	0.808	0.819	0.854	0.917	0.977	1.02	1.06	1.13
8<9	0.863	0.888	0.913	0.932	1.00	1.05	1.08	1.11	1.18
9<10	0.897	0.948	0.969	1.01	1.06	1.14	1.22	1.31	1.41
10<11	0.981	1.01	1.05	1.10	1.17	1.29	1.34	1.37	1.43
11<12	1.06	1.09	1.12	1.16	1.30	1.40	1.50	1.56	1.62
12<13	1.13	1.19	1.24	1.27	1.40	1.51	1.62	1.64	1.70
13<14	1.21	1.28	1.32	1.38	1.48	1.59	1.67	1.75	1.86
14<15	1.31	1.34	1.39	1.45	1.55	1.66	1.74	1.76	1.88
15<16	1.38	1.49	1.43	1.47	1.57	1.67	1.72	1.76	1.83
16<17	1.40	1.46	1.48	1.53	1.60	1.69	1.79	1.84	1.91
17<18	1.42	1.49	1.51	1.56	1.63	1.73	1.80	1.84	1.94
3<6	0.585	0.610	0.630	0.654	0.711	0.770	0.808	0.831	0.879
6<9	0.754	0.790	0.804	0.845	0.919	1.00	1.04	1.07	1.13
9<12	0.957	0.990	1.03	1.06	1.16	1.31	1.38	1.43	1.56
12<15	1.21	1.27	1.30	1.37	1.48	1.61	1.68	1.74	1.82
15<18	1.40	1.44	1.47	1.51	1.60	1.70	1.76	1.82	1.92

[a] Lack of height measurements for children <2 years in NHANES II precluded calculation of surface areas for this age group.
[b] Estimated values calculated using NHANES II data.
Source: U.S. EPA, 1985

Table 6-4. Surface Area by Body Part for Adults (m^2)

Body part	Men						Women					
	N[a]	Mean	(sd)[b]	Min	-	Max	N	Mean	(sd)	Min	-	Max
Head	32	0.118	(0.0160)	0.090	-	0.161	57	0.110	(0.00625)	0.0953	-	0.127
Trunk (Incl. Neck)	32	0.569	(0.104)	0.306	-	0.893	57	0.542	(0.0712)	0.437	-	0.867
Upper extremities	48	0.319	(0.0461)	0.169	-	0.429	57	0.276	(0.0241)	0.215	-	0.333
Arms	32	0.228	(0.0374)	0.109	-	0.292	13	0.210	(0.0129)	0.193	-	0.235
Upper arms	6	0.143	(0.0143)	0.122	-	0.156	-	-	-	-	-	-
Forearms	6	0.114	(0.0127)	0.0945	-	0.136	-	-	-	-		-
Hands	32	0.084	(0.0127)	0.0596	-	0.113	12	0.0746	(0.00510)	0.0639		0.0824
Lower extremities	48	0.636	(0.0994)	0.283	-	0.868	57	0.626	(0.0675)	0.492	-	0.809
Legs	32	0.505	(0.0885)	0.221	-	0.656	13	0.488	(0.0515)	0.423	-	0.585
Thighs	32	0.198	(0.1470)	0.128	-	0.403	13	0.258	(0.0333)	0.258	-	0.360
Lower legs	32	0.207	(0.0379)	0.093	-	0.296	13	0.194	(0.0240)	0.165	-	0.229
Feet	32	0.112	(0.0177)	0.0611	-	0.156	13	0.0975	(0.00903)	0.0834	-	0.115
TOTAL		1.94[c]	(0.00374)[d]	1.66	-	2.28[e]		1.69[c]	(0.00374)[d]	1.45	-	2.00[e]

[a] number of observations.
[b] standard deviation.
[c] median (see Table 6-2).
[d] standard error.
[e] percentiles (5th - 95th).
Source: Adapted from U.S. EPA, 1985

Table 6-5. Percentage of Total Body Surface Area by Part for Adults

Body part	Men						Women					
	N[a]	Mean	(s.d.)[b]	Min.	-	Max.	N	Mean	(s.d.)	Min.	-	Max.
Head	32	7.8	(1.0)	6.1	-	10.6	57	7.1	(0.6)	5.6	-	8.1
Trunk	32	35.9	(2.1)	30.5	-	41.4	57	34.8	(1.9)	32.8	-	41.7
Upper extremities	48	18.8	(1.1)	16.4	-	21.0	57	17.9	(0.9)	15.6	-	19.9
Arms	32	14.1	(0.9)	12.5	-	15.5	13	14.0	(0.6)	12.4	-	14.8
Upper arms	6	7.4	(0.5)	6.7	-	8.1	-	-	-	-	-	-
Forearms	6	5.9	(0.3)	5.4	-	6.3	-	-	-	-		-
Hands	32	5.2	(0.5)	4.6	-	7.0	12	5.1	(0.3)	4.4		5.4
Lower extremities	48	37.5	(1.9)	33.3	-	41.2	57	40.3	(1.6)	36.0	-	43.2
Legs	32	31.2	(1.6)	26.1	-	33.4	13	32.4	(1.6)	29.8	-	35.3
Thighs	32	18.4	(1.2)	15.2	-	20.2	13	19.5	(1.1)	18.0	-	21.7
Lower legs	32	12.8	(1.0)	11.0	-	15.8	13	12.8	(1.0)	11.4	-	14.9
Feet	32	7.0	(0.5)	6.0	-	7.9	13	6.5	(0.3)	6.0	-	7.0

[a] Number of observations.
[b] Standard deviation.
Source: Adapted from U.S. EPA, 1985

Table 6-2 Surface Area of Adult Males in Square Meters

Body part	Percentile									
	5	10	15	25	50	75	85	90	95	S.E.[a]
Total	1.66	1.72	1.76	1.82	1.94	2.07	2.14	2.20	2.28	0.00374
Head	0.119	0.121	0.123	0.124	0.130	0.135	0.138	0.140	0.143	0.0202
Trunk[b]	0.591	0.622	0.643	0.674	0.739	0.807	0.851	0.883	0.935[c]	0.0118
Upper extremities	0.321	0.332	0.340	0.350	0.372	0.395	0.408	0.418	0.432[c]	0.00101
Arms	0.241	0.252	0.259	0.270	0.291	0.314[c]	0.328[c]	0.339[c]	0.354[c]	0.00387
Forearms	0.106	0.111	0.115	0.121	0.131	0.144[c]	0.151[c]	0.157[c]	0.166[c]	0.0207
Hands	0.085	0.088	0.090	0.093	0.099	0.105	0.109	0.112	0.117	0.0187
Lower extremities	0.653	0.676	0.692	0.715	0.761	0.810	0.838	0.858	0.888[c]	0.00633
Legs	0.539	0.561	0.576	0.597	0.640	0.686[c]	0.714[c]	0.734[c]	0.762[c]	0.0130
Thighs	0.318	0.331	0.341	0.354	0.382	0.411[c]	0.429[c]	0.443[c]	0.463[c]	0.0149
Lower legs	0.218	0.226	0.232	0.240	0.256	0.272	0.282	0.288	0.299	0.0149
Feet	0.114	0.118	0.120	0.124	0.131	0.138	0.142	0.145	0.149	0.0147

[a] Standard error for the 5-95 percentile of each body part.
[b] Trunk includes neck.
[c] Percentile estimates exceed the maximum measured values upon which the equations are based.
Source: U.S. EPA, 1985

Table 6-3 Surface Area of Adult Females in Square Meters

Body part	Percentile									
	5	10	15	25	50	75	85	90	95	S.E.[a]
Total	1.45	1.49	1.53	1.58	1.69[c]	1.82	1.91	1.98	2.09	0.00374
Head	0.106	0.107	0.108	0.109	0.111	0.113	0.114	0.115	0.117	0.00678
Trunk[b]	0.490	0.507	0.518	0.538	0.579	0.636	0.677	0.704	0.752	0.00567
Upper extremities	0.260	0.265	0.269	0.274	0.287	0.301	0.311	0.318	0.329	0.00833
Arms	0.210	0.214	0.217	0.221	0.230	0.238[c]	0.243[c]	0.247[c]	0.253[c]	0.00996
Hands	0.0730	0.0746	0.0757	0.0777	0.0817	0.0868[c]	0.0903[c]	0.0927[c]	0.0966[c]	0.0172
Lower extremities	0.564	0.582	0.595	0.615	0.657	0.704	0.736	0.757	0.796	0.00633
Legs	0.460	0.477	0.488	0.507	0.546	0.592	0.623	0.645	0.683[c]	0.0130
Thighs	0.271	0.281	0.289	0.300	0.326	0.357	0.379	0.394	0.421[c]	0.0149
Lower legs	0.186	0.192	0.197	0.204	0.218	0.233	0.243	0.249	0.261	0.0149
Feet	0.100	0.103	0.105	0.108	0.114	0.121	0.126	0.129	0.134	0.0147

[a] Standard error for the 5-95 percentile of each body part.
[b] Trunk includes neck.
[c] Percentile estimates exceed the maximum measured values upon which the equations are based.
Source: U.S. EPA, 1985.

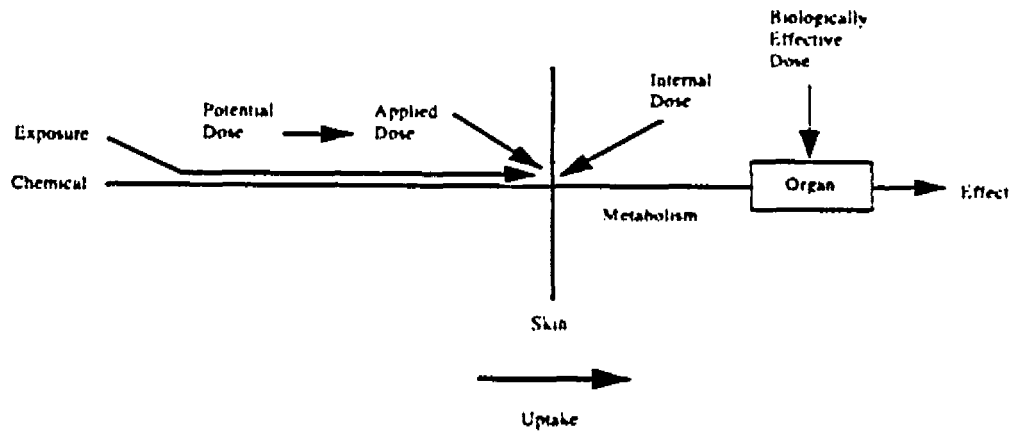


Figure 6-1. Schematic of Dose and Exposure: Dermal Route

Source: U.S. EPA, 1992a.

Table 6-1 Summary of Equation Parameters for Calculating Adult Body Surface Area

Body Part	N	Equation for surface areas (m^2) a_0	W^{a1}	H^{a2}	P	R^2	S.E.
Head							
Female	57	0.0256	0.124	0.189	0.01	0.302	0.00628
Male	32	0.0492	0.339	-0.0950	0.01	0.222	0.0202
Trunk							
Female	57	0.188	0.647	-0.304	0.001	0.877	0.00567
Male	32	0.0240	0.808	-0.0131	0.001	0.894	0.0118
Upper Extremities							
Female	57	0.0288	0.341	0.175	0.001	0.526	0.00833
Male	48	0.00329	0.466	0.524	0.001	0.821	0.0101
Arms							
Female	13	0.00223	0.201	0.748	0.01	0.731	0.00696
Male	32	0.00111	0.616	0.561	0.001	0.892	0.0177
Upper Arms							
Male	6	8.70	0.741	-1.40	0.25	0.576	0.0387
Forearms							
Male	6	0.326	0.858	-0.895	0.05	0.897	0.0207
Hands							
Female	12[b]	0.0131	0.412	0.0274	0.1	0.447	0.0172
Male	32	0.0257	0.573	-0.218	0.001	0.575	0.0187
Lower Extremities[c]	105	0.00286	0.458	0.696	0.001	0.802	0.00633
Legs	45	0.00240	0.542	0.626	0.001	0.780	0.0130
Thighs	45	0.00352	0.629	0.379	0.001	0.739	0.0149
Lower legs	45	0.000276	0.416	0.973	0.001	0.727	0.0149
Feet	45	0.000618	0.372	0.725	0.001	0.651	0.0147

a $SA = a_0 W^{a1} H^{a2}$
W = Weight in kilograms; H = Height in centimeters; P = Level of significance; R^2 = Coefficient of determination;
SA = Surface Area; S.E. = Standard error; N = Number of observations

b One observation for a female whose body weight exceeded the 95 percentile was not used.

c Although two separate regressions were marginally indicated by the F test, pooling was done for consistency with individual components of lower extremities.

Source: U.S. EPA, 1985

Sendroy, J.; Cecchini, L.P. (1954) Determination of human body surface area from height and weight. J. Appl. Physiol. 7(1):3-12.

Thompson, K.M.; Burmaster, D.E. (1991) Parametric distributions for soil ingestion by children. Risk. Anal. 11(2):339-342.

U.S. EPA. (1985) Development of statistical distributions or ranges of standard factors used in exposure assessments. Washington, DC: Office of Research and Development, Office of Health and Environmental Assessment. EPA 600/8-85-010. Available from: NTIS, Springfield, VA. PB85-242667.

U.S. EPA. (1989) Exposure factors handbook. Washington, DC: Office of Research and Development, Office of Health and Environmental Assessment. EPA/600/18-89/043.

U.S. EPA. (1992a) Guidelines for exposure assessment. Federal Register. FR 57:104:22888-22938. May 29, 1992.

U.S. EPA. (1992b) Dermal exposure assessment: principles and applications. Washington, DC: Office of Research and Development, Office of Health and Environmental Assessment/OHEA. U.S. EPA/600/8-9-91.

Van Graan, C.H. (1969) The determination of body surface area. Supplement to the South African J. of Lab. and Clin. Med. 8-2-69.

Versar, Inc. (1991) Analysis of the impact of exposure assumptions on risk assessment of chemicals in the environment, phase II: uncertainty analyses of existing exposure assessment methods. Draft Report. Prepared for Exposure Assessment Task Group, Chemical Manufacturers Association, Washington, DC.

Yang, J.J.; Roy, T.A.; Krueger, A.J.; Neil, W.; Mackerer, C.R. (1989) In vitro and in vivo percutaneous absorption of benzo[a]pyrene from petroleum crude-fortified soil in the rat. Bull. Environ. Contam. Toxicol. 43: 207-214.

6.5. REFERENCES FOR CHAPTER 6

American Industrial Health Council (AIHC). (1994) Exposure factors sourcebook. Washington, DC: AIHC.

Boyd, E. (1935) The growth of the surface area of the human body. Minneapolis, Minnesota: University of Minnesota Press.

Brainard, J.B.; Burmaster, D.E. (1992) Bivariate distributions for height and weight, men and women in the United States. Risk Anal. 12(2):267-275.

Brorby, G.; Finley B. (1993) Standard probability density functions for routine use in environmental health risk assessment. Presented at the Society of Risk Analysis Annual Meeting, December 1993, Savannah, GA.

Buhyoff, G.J.; Rauscher, H.M.; Hull, R.B.; Killeen, K.; Kirk, R.C. (1982) User's Manual for Statistical Processing System (version 3C.1). Southeast Technical Associates, Inc.

Costeff, H. (1966) A simple empirical formula for calculating approximate surface area in children. Arch. Dis. Childh. 41:681-683.

Driver, J.H.; Konz, J.J.; Whitmyre, G.K. (1989) Soil adherence to human skin. Bull. Environ. Contam. Toxicol. 43:814-820.

Dubois, D.; Dubois, E.F. (1916) A formula to estimate the approximate surface area if height and weight be known. Arch. of Intern. Med. 17:863-871.

Gehan, E.; George, G.L. (1970) Estimation of human body surface area from height and weight. Cancer Chemother. Rep. 54(4):225-235.

Geigy Scientific Tables (1981) Nomograms for determination of body surface area from height and mass. Lentner, C. (ed.). CIBA-Geigy Corporation, West Caldwell, NJ. pp. 226-227.

George, S.L.; Gehan, E.A.; Haycock, G.B.; Schwartz, G.J. (1979) Letters to the editor. J. Ped. 94(2):342.

Haycock, G.B.; Schwartz, G.J.; Wisotsky, D.H. (1978) Geometric method for measuring body surface area: A height-weight formula validated in infants, children, and adults. J. Ped. 93(1):62-66.

Holmes, K.K.; Kissel, J.C.; Richter,K.Y. (1996) Investigation of the influence of oil on soil adherence to skin. J. Soil Contam. 5(4):301-308.

Kissel, J.; Richter, K.; Duff, R.; Fenske, R. (1996a) Factors Affecting Soil Adherence to Skin in Hand-Press Trials. Bull. Environ. Contamin. Toxicol. 56:722-728.

Kissel, J.; Richter, K.; Fenske, R. (1996b) Field measurements of dermal soil loading attributable to various activities: Implications for exposure assessment. Risk Anal. 16(1):116-125.

Lepow, M.L.; Bruckman, L.; Gillette, M.; Markowitz, S.; Rubino, R.; Kapish, J. (1975) Investigations into sources of lead in the environment of urban children. Environ. Res. 10:415-426.

Murray, D.M.; Burmaster, D.E. (1992) Estimated distributions for total surface area of men and women in the United States. J. Expos. Anal. Environ. Epidemiol. 3(4):451-462.

Palisade. (1992) @Risk users guide. Palisade Corporation, Newfield, NY.

Phillips, L.J.; Fares, R.J.; Schweer, L.G. (1993) Distributions of total skin surface area to body weight ratios for use in dermal exposure assessments. J. Expos. Anal. Environ. Epidemiol. 3(3):331-338.

Popendorf, W.J.; Leffingwell, J.T. (1976) Regulating OP pesticide residues for farmworker protection. In: Residue Review 82. New York, NY: Springer-Verlag New York, Inc., 1982. pp. 125-201.

Que Hee, S.S.; Peace, B.; Clark, C.S.; Boyle, J.R.; Bornschein, R.L.; Hammond, P.B. (1985) Evolution of efficient methods to sample lead sources, such as house dust and hand dust, in the homes of children. Environ. Res. 38: 77-95.

Rochon, J.; Kalsbeek, W.D. (1983) Variance estimation from multi-stage sample survey data: the jackknife repeated replicate approach. Presented at 1983 SAS Users Group Conference, New Orleans, Louisiania, January 1983.

Roels, H.A.; Buchet, J.P.; Lauwenys, R.R.; Branx, P.; Claeys-Thoreau, F.; Lafontaine, A.; Verduyn, G. (1980) Exposure to lead by oral and pulmonary routes of children living in the vicinity of a primary lead smelter. Environ. Res. 22:81-94.

Sedman, R.M. (1989) The development of applied action levels for soil contact: a scenario for the exposure of humans to soil in a residential setting. Environ. Health Perspect. 79:291-313.

limited number of measurements. Specific situations have been selected to assess soil adherence to skin. Consequently, variation due to individuals, protective clothing, temporal, or seasonal factors remain to be studied in more detail. Therefore, caution is required in interpretation and application of these results for exposure assessments.

These studies are based on limited data, but suggest:

- Soil properties influence adherence. Adherence increases with moisture content, decreases with particle size, but is relatively unaffected by clay or organic carbon content.

- Adherence levels vary considerably across different parts of the body. The highest levels were found on common contact points such as hands, knees, and elbows; the least was detected on the face.

- Adherence levels vary with activity. In general, the highest levels of soil adherence were seen in outdoor workers such as farmers and irrigation system installers, followed by outdoor recreation, and gardening activities. Very high adherence levels were seen in individuals contacting wet soils such as might occur during wading or other shore area recreational activities.

In consideration of these general observations and the recent data from Kissel et al. (1996a, 1996b), changes are needed from past EPA recommendations which used one adherence value to represent all soils, body parts, and activities. One approach would be to select the activity from Table 6-11 which best represents the exposure scenario of concern and use the corresponding adherence value from Table 6-12. Although this approach represents an improvement, it still has shortcomings. For example, it is difficult to decide which activity in Table 6-12 is most representative of a typical residential setting involving a variety of activities. It may be useful to combine these activities into general classes of low, moderate, and high contact. In the future, it may be possible to combine activity-specific soil adherence estimates with survey-specific soil adherence estimates with survey-derived data on activity frequency and duration to develop overall average soil contact rates. EPA is sponsoring research to develop such an approach. As this information becomes availble, updated recommendations will be issued.

Table 6-12 provides the best estimates available on activity-specific adherence values, but are based on limited data. Therefore, they have a high degree of uncertainty such that considerable judgment must be used when selecting them for an assessment. The confidence ratings for various aspects of this recommendation are summarized in Table 6-18. Insufficient data are available to develop a distribution or a probability function for soil loadings.

Past EPA guidance has recommended assuming that soil exposure occurs primarily to exposed body surfaces and used typical clothing scenarios to derive estimates of exposed skin area. The approach recommended above for estimating soil adherence addresses this issue in a different manner. This change was motivated by two developments. First, increased acceptance that soil and dust particles can get under clothing and be deposited on skin. Second, recent studies of soil adherence have measured soil on entire body parts (whether or not they were covered by clothing) and averaged the amount of soil adhering to skin over the area of entire body part. The soil adherence levels resulting from these new studies must be combined with the surface area of the entire body part (not merely unclothed surface area) to estimate the amount of contaminant on skin. An important caveat, however, is that this approach assumes that clothing in the exposure scenario of interest matches the clothing in the studies used to derive these adherence levels such that the same degree of protection provided by clothing can be assumed in both cases. If clothing differs significantly between the studies reported here and the exposure scenarios under investigation, considerable judgment is needed to adjust either the adherence level or surface area assumption.

The dermal adherence value represents the amount of soil on the skin at the time of measurement. Assuming that the amount measured on the skin represents its accumulation between washings and that people wash at least once per day, these adherence values can be interpreted as daily contact rates (U.S. EPA, 1992b). However, this is not recommended because the residence time of soils on skin has not been studied. Instead, it is recommended that these adherence values be interpreted on an event basis (U.S. EPA, 1992b).

1985. Differences between the rat and human soil adhesion findings may be the result of differences in rat and human skin texture, the types of soils used, soil moisture content or possibly the methods of measuring soil adhesion (Yang et al., 1989).

6.4. RECOMMENDATIONS

6.4.1. Body Surface Area

Body surface area estimates are based on direct measurements. Re-analysis of data collected by Boyd (1935) by several investigators (Gehan and George, 1970; U.S. EPA, 1985; Murray and Burmaster, 1992; Phillips et al., 1993) constitutes much of this literature. Methods are highly reproducible and the results are widely accepted. The representativeness of these data to the general population is somewhat limited since variability due to race or gender have not been systematically addressed.

Individual body surface area studies are summarized in Table 6-13 and the recommendations for body surface area are summarized in Table 6-14. Table 6-15 presents the confidence ratings for various aspects of the recommendations for body surface area. The U.S. EPA (1985) study is based on generally accepted measurements that enjoy widespread usage, summarizes and compares previous reports in the literature, provides statistical distributions for adults, and provides data for total body surface area and body parts by gender for adults and children. However, the results are based on 401 selected measurements from the original 1,114 made by Boyd (1935). More than half of the measurements are from children. Therefore, these estimates may be subject to selection bias and may not be representative of the general population nor specific ethnic groups. Phillips et al. (1993) analyses are based on direct measurement data that provide distributions of body surface area to calculate LADD. The results are consistent with previous efforts to estimate body surface area. Analyses are based on 401 measurements selected from the original 1,114 measurements made by Boyd (1935) and data were not analyzed for specific body parts. The study by Murray and Burmaster (1992) provides frequency distributions for body surface area for men and women and produces results that are similar to those obtained by the U.S. EPA (1985), but do not provide data for body parts nor can results be applied to children.

For most dermal exposure scenarios concerning adults, it is recommended that the body surface areas presented in Table 6-4 be used after determining which body parts will be exposed. Table 6-4 was selected because these data are straightforward determinations for most scenarios. However, for others, additional considerations may need to be addressed. For example, (1) the type of clothing worn could have a significant effect on the surface area exposed, and (2) climatic conditions will also affect the type of clothing worn and, thus, the skin surface area exposed.

Frequency, event, and exposure duration for water activities and soil contact are presented in Activity Patterns, Volume III, Chapter 15 of this report. For each parameter, recommended values were derived for average and upper percentile values. Each of these considerations are also discussed in more detail in U.S. EPA (1992b). Data in Tables 6-2 and 6-3 can be used when surface area distributions are preferred. A range of recommended values for estimates of the skin surface area of children may be taken from Tables 6-6 and 6-7 using the 50th and 95th percentile values for age(s) of concern. The recommended 50th and 95th percentile values for adult skin surface area provided in U.S. EPA (1992b) are presented in Table 6-16.

6.4.2. Soil Adherence to Skin

Table 6-17 summarizes the relevant and key studies addressing soil adherence to skin. Both Lepow et al. (1975) and Roels et al. (1980) monitored typical exposures in children. They attempted to estimate typical exposure by recovery of accumulated soil from hands at specific time intervals. The efficiency of their sample collection methods is not known and may be subject to error. Only children were studied which may limit generalizing these results to adults. Later studies (Que Hee et al., 1985 and Driver et al., 1989) attempted to characterize both soil properties and sample collection efficiency to estimate adherence of soil to skin. However, the experimental conditions used to expose skin to soil may not reflect typical dermal exposure situations. This provides useful information about the influence of soil characteristics on skin adherence, but the intimate contact of skin with soil required under the controlled experimental conditions in the studies by Driver et al. (1989) and Que Hee et al. (1985) may have exaggerated the amount of adherence over what typically occurs.

More recently, Kissel et al. (1996a; 1996b) have related dermal adherence to soil characteristics and to specific activities. In all cases, experimental design and measurement methods are straightforward and reproducible, but application of results is limited. Both controlled experiments and field studies are based on a

estimate the amount of soil adhering to the hands. The mean soil amount adhering to the hands was 0.159 grams.

Que Hee et al. (1985) - Evolution of Efficient Methods to Sample Lead Sources, Such as House Dust and Hand Dust, in the Homes of Children - Que Hee et al. (1985) used soil having particle sizes ranging from < 44 to 833 µm diameters, fractionated into six size ranges, to estimate the amount that adhered to the palm of the hand that are assumed to be approximately 160 cm^2 (test subject with an average total body surface area of 16,000 cm^2 and a total hand surface area of 400 cm^2). The amount of soil that adhered to skin was determined by applying approximately 5 g of soil for each size fraction, removing excess soil by shaking the hands, and then measuring the difference in weight before and after application. Several assumptions were made to apply these results to other soil types and exposure scenarios: (a) the soil is composed of particles of the indicated diameters; (b) all soil types and particle sizes adhere to the skin to the degree observed in this study; and an equivalent weight of particles of any diameter adhere to the same surface area of skin. On average, 31.2 mg of soil adhered to the palm of the hand.

Driver et al. (1989) - Soil Adherence to Human Skin - Driver et al. (1989) conducted soil adherence experiments using various soil types collected from sites in Virginia. A total of five soil types were collected: Hyde, Chapanoke, Panorama, Jackland, and Montalto. Both top soils and subsoils were collected for each soil type. The soils were also characterized by cation exchange capacity, organic content, clay mineralogy, and particle size distribution. The soils were dry sieved to obtain particle sizes of ≤250 µm and ≤150 µm. For each soil type, the amount of soil adhering to adult male hands, using both sieved and unsieved soils, was determined gravimetrically (i.e., measuring the difference in soil sample weight before and after soil application to the hands).

An attempt was made to measure only the minimal or "monolayer" of soil adhering to the hands. This was done by mixing a pre-weighed amount of soil over the entire surface area of the hands for a period of approximately 30 seconds, followed by removal of excess soil by gently rubbing the hands together after contact with the soil. Excess soil that was removed from the hands was collected, weighed, and compared to the original soil sample weight. The authors measured average adherence of 1.40 mg/cm^2 for particle sizes less than 150 µm, 0.95 mg/cm^2 for particle sizes less than 250 µm, and 0.58 mg/cm^2 for unsieved soils. Analysis of variance statistics showed that the most important factor affecting adherence variability was particle size ($p < 0.001$). The next most important factor is soil type and subtype ($p < 0.001$). The interaction of soil type and particle size was also significant, but at a lower significance level ($p < 0.01$).

Driver et al. (1989) found statistically significant increases in soil adherence with decreasing particle size; whereas, Que Hee et al. (1985) found relatively small changes with changes in particle size. The amount of soil adherence found by Driver et al. (1989) was greater than that reported by Que Hee et al. (1985).

Sedman (1989) - The Development of Applied Action Levels for Soil Contact: A Scenario for the Exposure of Humans to Soil in a Residential Setting - Sedman (1989) used the estimate from Roels et al. (1980), 0.159 g, and the average surface area of the hand of an 11 year old, 307 cm^2 to estimate the amount of soil adhering per unit area of skin to be 0.9 mg/cm^2. This assumed that approximately 60 percent (185 cm^2) of the lead on the hands was recovered by the method employed by Roels et al. (1980).

Sedman (1989) used estimates from Lepow et al. (1975), Roels et al. (1980), and Que Hee et al. (1985) to develop a maximum soil load that could occur on the skin. A rounded arithmetic mean of 0.5 mg/cm^2 was calculated from these three studies. According to Sedman (1989), this was near the maximum load of soil that could occur on the skin but it is unlikely that most skin surfaces would be covered with this amount of soil (Sedman, 1989).

Yang et al. (1989) - In vitro and In vivo Percutaneous Absorption of Benzo[a]pyrene from Petroleum Crude - Fortified Soil in the Rat - Yang et al. (1989) evaluated the percutaneous absorption of benzo[a]pyrene (BAP) in petroleum crude oil sorbed on soil using a modified in vitro technique. This method was used in preliminary experiments to determine the minimum amount of soil adhering to the skin of rats. Based on these results, percutaneous absorption experiments with the crude-sorbed soil were conducted with soil particles of <150 µm only. This particle size was intended to represent the composition of the soil adhering to the skin surface. Approximately 9 mg/cm^2 of soil was found to be the minimum amount required for a "monolayer" coverage of the skin surface in both in vitro and in vivo experiments. This value is larger than reports for human skin in the studies of Kissel et al., 1996a,b; Lepow et al., 1975; Roels et al., 1980; and Que Hee et al.,

Table 6-18. Confidence in Soil Adherence to Skin Recommendations

Considerations	Rationale	Rating
Study Elements		
• Level of Peer Review	Studies were from peer reviewed journal articles.	High
• Accessibility	Articles were published in widely circulated journals.	High
• Reproducibility	Reports clearly describe experimental method.	High
• Focus on factor of interest	The goal of the studies was to determine soil adherence to skin.	High
• Data pertinent to U.S.	Experiments were conducted in the U.S.	High
• Primary data	Experiments were directly measure soil adherence to skin; exposure and dose of chemicals in soil were measured indirectly or estimated from soil contact.	High
• Currency	New studies were presented.	High
• Adequacy of data collection period	Seasonal factors may be important, but have not been studied adequately.	Medium
• Validity of approach	Skin rinsing technique is a widely employed procedure.	High
• Representativeness of the population	Studies were limited to the State of Washington and may not be representative of other locales.	Low
• Characterization of variability	Variability in soil adherence is affected by many factors including soil properties, activity and individual behavior patterns.	Low
• Lack of bias in study design	The studies attempted to measure soil adherence in selected activities and conditions to identify important activities and groups.	High
• Measurement error	The experimental error is low and well controlled, but application of results to other similar activities may be subject to variation.	Low/High
Other Elements		
• Number of studies	The experiments were controlled as they were conducted by a few laboratories; activity patterns were studied by only one laboratory.	Medium
• Agreement among researchers	Results from key study were consistent with earlier estimates from relevant studies and assumptions, but are limited to hand data.	Medium
Overall Rating	Data are limited, therefore it is difficult to extrapolate from experiments and field observations to general conditions .	Low

Table 6-16. Recommendations for Adult Body Surface Area		
	Water Contact	
	50th	95th
Bathing and Swimming	20,000 cm^2	23,000 cm^2
	Soil Contact	
	50th	95th
Outdoor Activities	5,000 cm^2	5,800 cm^2
Source: U.S. EPA, 1992.		

Table 6-17. Summary of Soil Adherence Studies

Study	Size Fraction (µm)	Soil Adherence (mg/cm^2)	Population Surveyed	Comments
KEY STUDIES				
Kissel et al., 1995a	<150, 150-200, >250	Various	28 adults 24 children	Data presented for soil loadings by body part. See Table 6-11.
Kissell et al., 1996b	--	Various	12 children 89 adults	Data presented by activity and body part.
RELEVANT STUDIES				
Driver et al., 1989	<150 <250 unsieved	1.40 0.95 0.58	Adults Adults Adults	Used 5 soil types and 2-3 soil horizons (top soils and subsoils); placed soil over entire hand of test subject, excess removed by shaking the hands.
Lepow et al., 1975	--	0.5	10 children	Dirt from hands collected during play. Represents only fraction of total present, some dirt may be trapped in skin folds.
Que Hee et al., 1985	--	1.5	1 adult	Assumed exposed area = 20 cm^2. Test subject was 14 years old.
Roels et al., 1980	--	0.9-1.5	661 children	Subjects lived near smelter in Brussels, Belgium. Mean amount adhering to soil was 0.159 g.
Sedman, 1989	--	0.9; 0.5	Children	Used estimate of Roels et al. (1980) and average surface of hand of an 11 year old; used estimates of Lepow et al. (1975), Roels et al. (1980), and Que Hee et al. (1985) to develop mean of 0.5 mg/cm^2.
Yang et al., 1989	<150	9	Rats	Rat skin "monolayer" (i.e., minimal amount of soil covering the skin); in vitro and in vivo experiments

Table 6-14. Summary of Recommended Values for Skin Surface Area

Surface Area	Central Tendency	Upper Percentile	Multiple Percentiles
Adults			
Whole body and body parts	see Tables 6-4 and 6-5	see Tables 6-2 and 6-3	see Tables 6-2 and 6-3
Bathing/swimming	20,000 cm^2	23,000 cm^2	—
Outdoor soil contact	5,000 cm^2	5,800 cm^2	—
Children			
Whole body	—	see Tables 6-6 and 6-7	see Tables 6-6 and 6-7
Body parts	—	see Table 6-8	see Table 6-8

Table 6-15. Confidence in Body Surface Area Measurement Recommendations

Considerations	Rationale	Rating
Study Elements		
• Level of Peer Review	Studies were from peer reviewed journal articles. EPA report was peer reviewed before distribution.	High
• Accessibility	The journals used have wide circulation. EPA report available from National Technical Information Service.	High
• Reproducibility	Experimental methods are well-described.	High
• Focus on factor of interest	Experiments measured skin area directly.	High
• Data pertinent to U.S.	Experiments conducted in the U.S.	High
• Primary data	Re-analysis of primary data in more detail by two different investigators.	Low
• Currency	Neither rapidly changing nor controversial area; estimates made in 1935 deemed to be accurate and subsequently used by others.	Low
• Adequacy of data collection period	Not relevant to exposure factor; parameter not time dependent.	NA
• Validity of approach	Approach used by other investigators; not challenged in other studies.	High
• Representativeness of the population	Not statistically representative of U.S. population.	Medium
• Characterization of variability	Individual variability due to age, race, or gender not studied.	Low
• Lack of bias in study design	Objective subject selection and measurement methods used; results reproduced by others with different methods.	High
• Measurement error	Measurement variations are low; adequately described by normal statistics.	Low/Medium
Other Elements		
• Number of studies	1 experiment; two independent re-analyses of this data set.	Medium
• Agreement among researchers	Consistent results obtained with different analyses; but from a single set of measurements.	Medium
Overall Rating	This factor can be directly measured. It is not subject to dispute. Influence of age, race, or gender have not been detailed adequately in these studies.	High

Table 6.13 Summary of Surface Area Studies

Study	Surface Area				
	No. of Individuals	Type of Surface Area Measurement	Recommended Formulae Used	Population Surveyed	Comments
KEY STUDIES					
Phillips et al (1993)	Based on data from U.S. EPA (1985) 401 individuals	NA	calculated surface area to body weight ratios	Children Adults	Developed distributions of SA/BW and calculated summary statistics for 3 age groups and the combined data set
U.S. EPA (1985)	401 individuals	Based on Gehan and George (1970)	$SA=0.0239*W^{0.517}*H^{0.417}$	Children Adults	Provides statistical distribution data for total SA and SA of body parts
RELEVANT STUDIES					
AICH (1994)	Based on data from U.S. EPA (1989), Brainard et al. (1991), Brasby and Finley (1993)	@Risk simulation software	Various	Adults Children	Distribution data for: adult men and women and both sexes combined, total skin area, children 3-18 years; exposed skin area (hands and forearms), head, upper body
Murray and Burmaster (1992)	Based on data from U.S. EPA (1985) N = 401, Dubois and Dubois (1976) N = 9, Boyd (1935) N = 231, Costeff (1966) N = 220	Calculated based on regression equation using the data of U.S. EPA (1985)	Various	Children Adults	Analysis of and comparision of four models developed by Dubois & Dubois (1916), Boyd (1935), U.S. EPA (1985), and Costeff (1966). Presents frequency distributions

Table 6-12. Geometric Mean and Geometric Standard Deviations of Soil Adherence by Activity and Body Region (continued)

Activity	N*	Post-activity Dermal Soil Loadings (mg/cm2)				
		Hands	Arms	Legs	Faces	Feet
Gardeners No. 2	7	0.18 3.4	0.054 2.9	0.022 2.0	0.047 1.6	0.26 –
Rugby No. 1	8	0.40 1.7	0.27 1.6	0.36 1.7	0.059 2.7	
Rugby No. 2	8	0.14 1.4	0.11 1.6	0.15 1.6	0.046 1.4	
Rugby No. 3	7	0.049 1.7	0.031 1.3	0.057 1.2	0.020 1.5	
Archeologists	7	0.14 1.3	0.041 1.9	0.028 4.1	0.050 1.8	0.24 1.4
Construction Workers	8	0.24 1.5	0.098 1.5	0.066 1.4	0.029 1.6	
Utility Workers No.1	5	0.32 1.7	0.20 2.7		0.10 1.5	
Utility Workers No. 2	6	0.27 2.1	0.30 1.8		0.10 1.5	
Equip. Operators No. 1	4	0.26 2.5	0.089 1.6		0.10 1.4	
Equip. Operators No. 2	4	0.32 1.6	0.27 1.4		0.23 1.7	
Farmers No. 1	4	0.41 1.6	0.059 3.2	0.0058 2.7	0.018 1.4	
Farmers No. 2	6	0.47 1.4	0.13 2.2	0.037 3.9	0.041 3.0	
Reed Gatherers	4	0.66 1.8	0.036 2.1	0.16 9.2		0.63 7.1
Kids-in-mud No. 1	6	35 2.3	11 6.1	36 2.0		24 3.6
Kids-in-mud No. 2	6	58 2.3	11 3.8	9.5 2.3		6.7 12.4

* Number of subjects.
Sources: Kissel et al., 1996b; Holmes et al., 1996 (submitted for publication)

Table 6-12. Geometric Mean and Geometric Standard Deviations of Soil Adherence by Activity and Body Region

Activity	N*	Post-activity Dermal Soil Loadings (mg/cm2)				
		Hands	Arms	Legs	Faces	Feet
Indoor						
Tae Kwon Do	7	0.0063 1.9	0.0019 4.1	0.0020 2.0		0.0022 2.1
GreenhouseWorkers	2	0.043 --	0.0064 --	0.0015 --	0.0050 --	
Indoor Kids No. 1	4	0.0073 1.9	0.0042 1.9	0.0041 2.3		0.012 1.4
Indoor Kids No. 2	6	0.014 1.5	0.0041 2.0	0.0031 1.5		0.0091 1.7
Daycare Kids No. 1a	6	0.11 1.9	0.026 1.9	0.030 1.7		0.079 2.4
Daycare Kids No. 1b	6	0.15 2.1	0.031 1.8	0.023 1.2		0.13 1.4
Daycare Kids No. 2	5	0.073 1.6	0.023 1.4	0.011 1.4		0.044 1.3
Daycare Kids No. 3	4	0.036 1.3	0.012 1.2	0.014 3.0		0.0053 5.1
Outdoor						
Soccer No. 1	8	0.11 1.8	0.011 2.0	0.031 3.8	0.012 1.5	
Soccer No. 2	8	0.035 3.9	0.0043 2.2	0.014 5.3	0.016 1.5	
Soccer No. 3	7	0.019 1.5	0.0029 2.2	0.0081 1.6	0.012 1.6	
Groundskeepers No. 1	2	0.15 --	0.005 --		0.0021 --	0.018 --
Groundskeepers No. 2	5	0.098 2.1	0.0021 2.6	0.0010 1.5	0.010 2.0	
Groundskeepers No. 3	7	0.030 2.3	0.0022 1.9	0.0009 1.8	0.0044 2.6	0.0040
Groundskeepers No. 4	7	0.045 1.9	0.014 1.8	0.0008 1.9	0.0026 1.6	0.018 --
Groundskeepers No. 5	8	0.032 1.7	0.022 2.8	0.0010 1.4	0.0039 2.1	
Landscape/Rockery	4	0.072 2.1	0.030 2.1		0.0057 1.9	
Irrigation Installers	6	0.19 1.6	0.018 3.2	0.0054 1.8	0.0063 1.3	
Gardeners No. 1	8	0.20 1.9	0.050 2.1	0.072 --	0.058 1.6	0.17 --

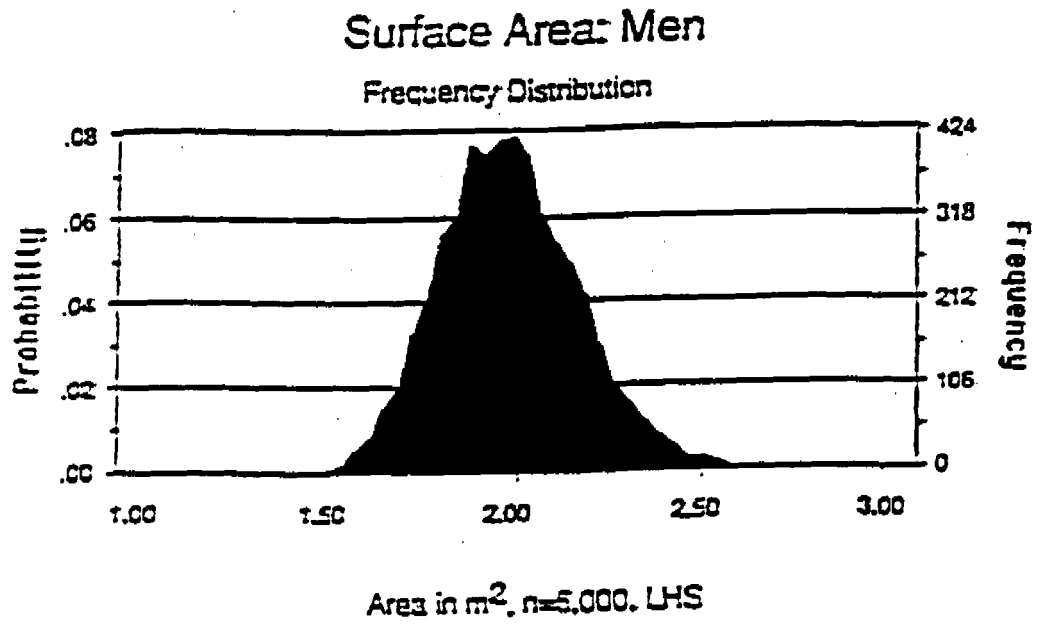
Table 6-11. Summary of Field Studies (continued)

Activity	Month	Event[a] (hrs)	N[b]	M	F	Age	Conditions	Clothing
Gardeners No. 2	Aug.	4	7	2	5	26-52	Weeding, pruning, digging a trench, picking fruit, cleaning	3 of 7 long pants, 5of 7 short sleeves, 1 sleeveless, socks, shoes, no gloves
Rugby No. 1	Mar.	1.75	8	8	0	20-22	Mixed grass-barewet field	All in short sleeve shirts, shorts, variable sock lengths
Rugby No. 2	July	2	8	8	0	23-33	Grass field (80% oftime) and all-weather field (mix of gravel, sand, and clay) (20% oftime)	All in shorts, 7 of 8 in short sleeve shirts, 6 of 8 in low socks
Rugby No. 3	Sept.	2.75	7	7	0	24-30	Compacted mixedgrass and bare earth field	All short pants, 7 of 8 short or rolled up sleeves, socks, shoes
Archeologists	July	11.5	7	3	4	16-35	Digging withtrowel, screening dirt, sorting	6 of 7 short pants,all short sleeves, 3 no shoes or socks, 2 sandals
Construction Workers	Sept.	8	8	8	0	21-30	Mixed bare earth and concrete surfaces, dust and debris	5 of 8 pants,7 of 8 short sleeves, all socks and shoes
Utility Workers No.1	July	9.5	5	5	0	24-45	Cleaning, fixing mains, excavation (backhoe and shovel)	All long pants,short sleeves, socks, boots, gloves sometimes
Utility Workers No.2	Aug.	9.5	6	6	0	23-44	Cleaning, fixing mains, excavation (backhoe and shovel)	All long pants, 5 of 6 short sleeves, socks, boots, gloves sometimes
Equip. Operators No.1	Aug.	8	4	4	0	21-54	Earth scraping withheavy machinery, dusty conditions	All long pants, 3 of 4 short sleeves, socks, boots, 2 of 4 gloves
Equip. Operators No.2	Aug.	8	4	4	0	21-54	Earth scraping withheavy machinery, dusty conditions	All long pants, 3 of 4 short sleeves, socks, boots, 1 gloves
Farmers No. 1	May	2	4	2	2	39-44	Manual weeding,mechanical cultivation	All in long pants, heavy shoes, short sleeve shirts, no gloves
Farmers No. 2	July	2	6	4	2	18-43	Manual weeding,mechanical cultivation	2 of 6 short, 4 of 6long pants, 1 of 6 long sleeve shirt, no gloves
Reed Gatherers	Aug.	2	4	0	4	42-67	Tidal flats	2 of 4 shortsleeve shirts/knee length pants, all wore shoes
Kids-in-mud No. 1	Sept.	0.17	6	5	1	9-14	Lake shoreline	All in short sleeve T-shirts, shorts, barefoot
Kids-in-mud No. 2	Sept.	0.33	6	5	1	9-14	Lake shoreline	All in short sleeveT-shirts, shorts, barefoot
		Outdoor Totals	*181*	*125*	*56*			

a Event duration
b Number of subject
c Activities were confined to the house
Sources: Kissel et al., 1996b; Holmes et al., 1996 (submitted for publication).

Table 6-11 Summary of Field Studies

Activity	Month	Event[a] (hrs)	N[b]	M	F	Age	Conditions	Clothing
Indoor								
Tae Kwon Do	Feb.	1.5	7	6	1	8-42	Carpeted floor	All in longsleeve-long pants martial arts uniform, sleeves rolled back, barefoot
Greenhouse Workers	Mar.	5.25	2	1	1	37-39	Plant watering,spraying, soil blending, sterilization	Long pants, elbow length short sleeve shirt, no gloves
Indoor Kids No. 1	Jan.	2	4	3	1	6-13	Playing on carpeted floor	3 of 4 short pants, 2 of 4 short sleeves, socks, no shoes
Indoor Kids No. 2	Feb.	2	6	4	2	3-13	Playing on carpeted floor	5of 6 long pants, 5 of 6 long sleeves, socks, no shoes
		Indoor Totals	*19*		*14*	*5*		
Outdoor								
Daycare Kids No 1a	Aug.	3.5	6	5	1	1-6.5	Indoors: linoleum surface; outdoors: grass, bare earth, barked area	4 of 6 in long pants, 4 of 6 short sleeves, shoes
Daycare Kids No. 1b	Aug.	4	6	5	1	1-6.5	Indoors: linoleum surface; outdoors: grass, bare earth, barked area	4 of 6 in long pants, 4 of 6 short sleeves, no shoes
Daycare Kids No.2c	Sept.	8	5	4	1	1-4	Indoors, low napped carpeting, linoleum surfaces	4 of 5 long pants, 3of 5 long sleeves, all barefoot for part of the day
Daycare Kids No. 3	Nov.	8	4	3	1	1-4.5	Indoors: linoleum surface, outside: grass, bare earth, barked area	All long pants, 3 of 4 long sleeves, socks and shoes
Soccer No. 1	Nov.	0.67	8	8	0	13-15	Half grass-half bare earth	6 of 8 long sleeves, 4 of 8 long pants, 3 of 4 short pants and shin guards
Soccer No. 2	Mar.	1.5	8	0	8	24-34	All-weather field (sand-ground tires)	All in short sleeve shirts, shorts, knee socks, shin guards
Soccer No. 3	Nov.	1.5	7	0	7	24-34	All-weather field (sand-ground tires)	All in short sleeve shirts, shorts, knee socks, shin guards
Groundskeepers No. 1	Mar.	1.5	2	1	1	29-52	Campus grounds, urban horticulture center, arboretum	All in long pants, intermittent use of gloves
Groundskeepers No. 2	Mar.	4.25	5	3	2	22-37	Campus grounds,urban horticulture center, arboretum	All in long pants, intermittent use of gloves
Groundskeepers No. 3	Mar.	8	7	5	2	30-62	Campus grounds,urban horticulture center, arboretum	All in long pants, intermittent use of gloves
Groundskeepers No. 4	Aug.	4.25	7	4	3	22-38	Campus grounds,urban horticulture center, arboretum	5 of 7 in short sleeve shirts, intermittent use of gloves
Groundskeepers No. 5	Aug.	8	8	6	2	19-64	Campus grounds,urban horticulture center, arboretum	5 of 8 in short sleeve shirts, intermittent use of gloves
Landscape/Rockery	June	9	4	3	1	27-43	Digging (manual andmechanical), rock moving	All long pants, 2 long sleeves, all socks and boots
IrrigationInstallers	Oct.	3	6	6	0	23-41	Landscaping,surface restoration	All in long pants, 3 of 6 short sleeve or sleeveless shirts
Gardeners No. 1	Aug.	4	8	1	7	16-35	Weeding, pruning,digging a trench	6 of 8 long pants, 7 of 8 short sleeves, 1 sleeveless, socks, shoes, intermittent use of gloves



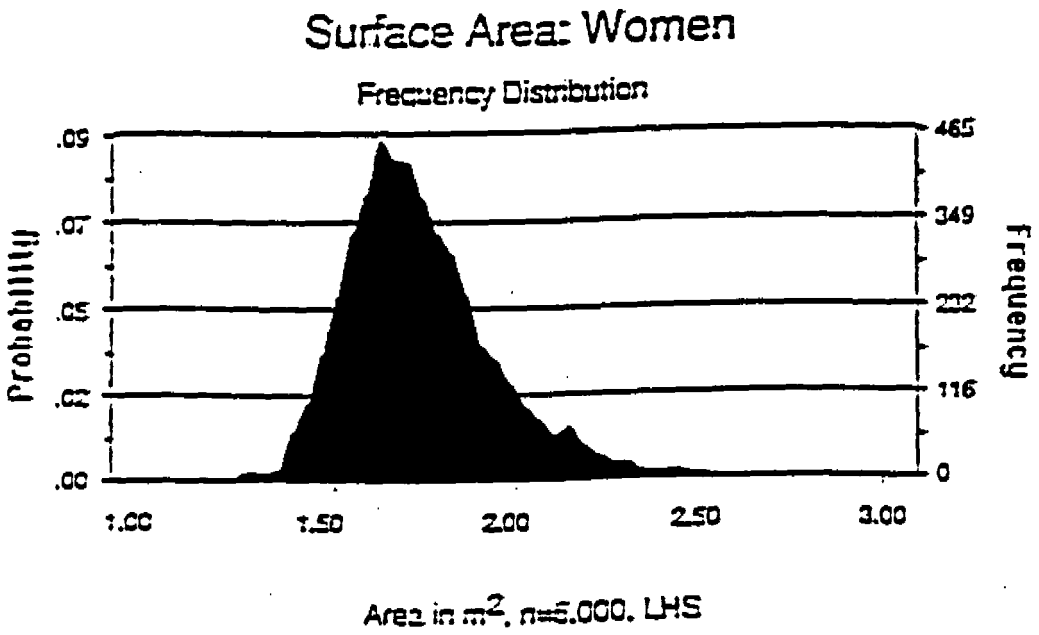


Figure 6-3. Frequency Distributions for the Surface Area of Men and Women
Source: Murray and Burmaster, 1992.

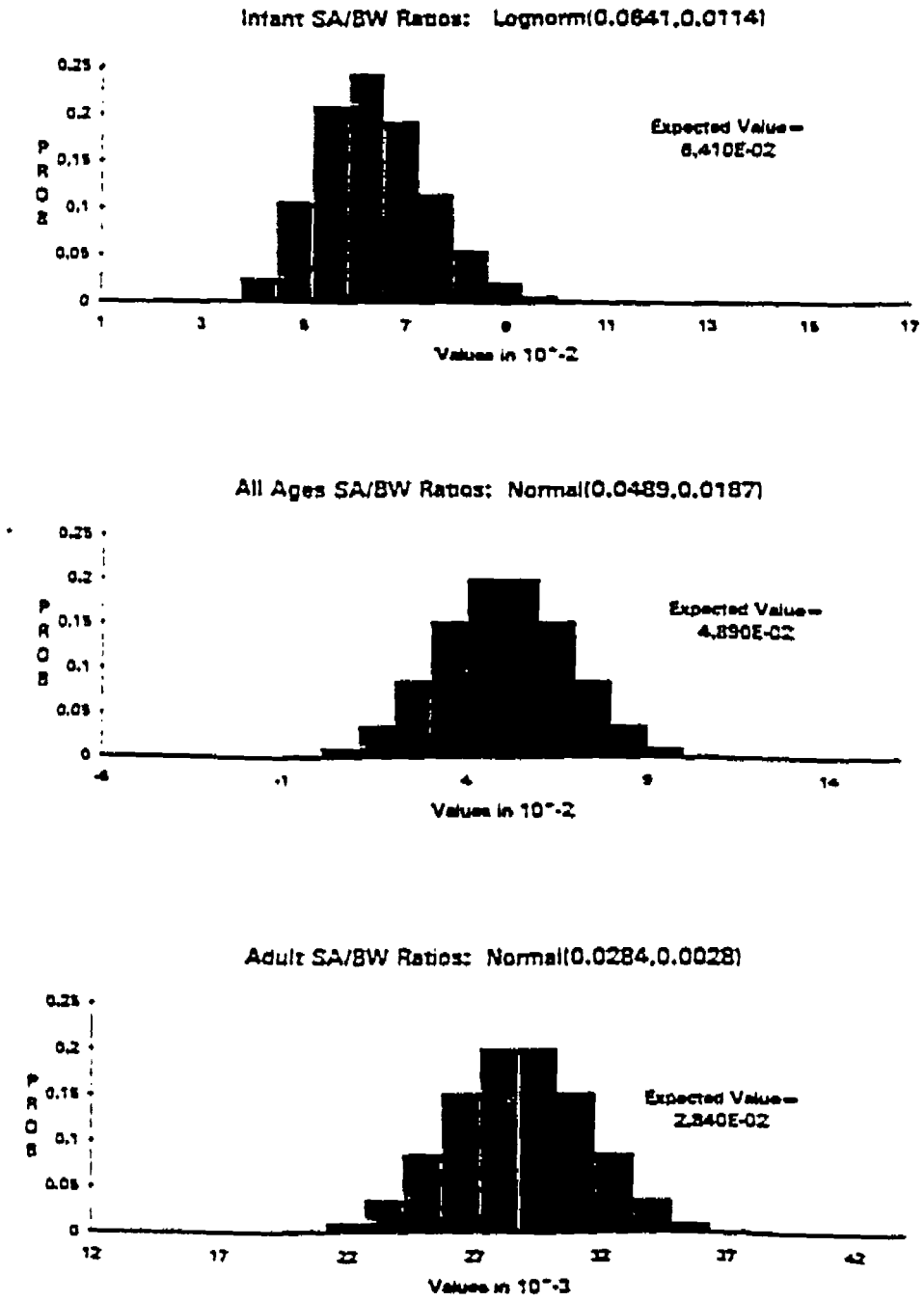


Figure 6-2. SA/BW Distributions for Infants, Adults, and All Ages Combined
Source: Phillips et al., 1993.

Table 6-9 Descriptive Statistics for Surface Area/Body Weight (SA/BW) Ratios (m^2/kg)

Age (yrs.)	Mean	Range Min-Max	SD[a]	SE[b]	Percentiles 5	10	25	50	75	90	95
0-2	0.0641	0.0421-0.1142	0.0114	7.84e-4	0.0470	0.0507	0.0563	0.0617	0.0719	0.0784	0.0846
21 - 17.9	0.0423	0.0268-0.0670	0.0076	1.05e-3	0.0291	0.0328	0.0376	0.0422	0.0454	0.0501	0.0594
> 18	0.0284	0.0200-0.0351	0.0028	7.68e-6	0.0238	0.0244	0.0270	0.0286	0.0302	0.0316	0.0329
All ages	0.0489	0.0200-0.1142	0.0187	9.13e-4	0.0253	[illegible]	0.0290	0.0405	0.0631	0.0740	0.0788

[a] Standard deviation.
[b] Standard error of the mean.
Source: Phillips et al., 1993

Table 6-10 Statistical Results for Total Body Surface Area Distributions (m^2)

	U.S. EPA	Boyd	Dallos and Dallos	Costeff
Men				
Mean	1.97	1.95	1.94	1.89
Median	1.96	1.94	1.94	1.89
Mode	1.96	1.91	1.90	1.90
Standard Deviation	0.19	0.18	0.17	0.16
Skewness	0.27	0.26	0.23	0.04
Kurtosis	3.08	3.06	3.02	2.92
Women				
Mean	1.73	1.71	1.69	1.71
Median	1.69	1.68	1.67	1.68
Mode	1.68	1.62	1.60	1.66
Standard Deviation	0.21	0.20	0.18	0.21
Skewness	0.92	0.88	0.77	0.69
Kurtosis	4.30	4.21	4.01	3.52

Source: Murray and Burmaster, 1995

It has been determined that the Gehan and George model is the formula of choice for estimating total surface area of the body since it is based on the largest number of direct measurements.

Nomograms

Sendroy and Cecchini (1954) proposed a graphical method whereby surface area could be read from a diagram relating height and weight to surface area. However, they do not give an explicit model for calculating surface area. The graph was developed empirically based on 252 cases, 127 of which were from the 401 direct measurements reported by Boyd (1935). In the other 125 cases the surface area was estimated using the linear method of DuBois and DuBois (1916). Because the Sendroy and Cecchini method is graphical, it is inherently less precise and less accurate than the formulae of other authors discussed above.

Haycock et al. (1978) without knowledge of the work by Gehan and George (1970), developed values for the parameters a_0, a_1, and a_2 for the DuBois and DuBois model. Their interest in making the DuBois and DuBois model more accurate resulted from their work in pediatrics and the fact that DuBois and DuBois (1916) included only one child in their study group, a severely undernourished girl who weighed only 13.8 pounds at age 21 months. Haycock et al. (1978) used their own geometric method for estimating surface area from 34 body measurements for 81 subjects. Their study included newborn infants (10 cases), infants (12 cases), children (40 cases), and adult members of the medical and secretarial staffs of 2 hospitals (19 cases). The subjects all had grossly normal body structure, but the sample included subjects of widely varying physique ranging from thin to obese. Black, Hispanic, and white children were included in their sample. The values of the model parameters were solved for the relationship between surface area and height and weight by multiple regression analysis. The least squares best fit for this equation yielded the following values for the three coefficients: $a_0 = 0.024265$, $a_1 = 0.3964$, and $a_2 = 0.5378$. The result was the following equation for estimating surface area:

$$SA = 0.024265\ H^{0.3964}\ W^{0.5378} \qquad \text{(Eqn. 6A-9)}$$

expressed logarithmically as:

$$\ln SA = \ln 0.024265 + 0.3964 \ln H + 0.5378 \ln W \qquad \text{(Eqn. 6A-10)}$$

The coefficients for this equation agree remarkably with those obtained by Gehan and George (1970) for 401 measurements.

George et al. (1979) agree that a model more complex than the model of DuBois and DuBois for estimating surface area is unnecessary. Based on samples of direct measurements by Boyd (1935) and Gehan and George (1970), and samples of geometric estimates by Haycock et al. (1978), these authors have obtained parameters for the DuBois and DuBois model that are different than those originally postulated in 1916. The DuBois and DuBois model can be written logarithmically as:

$$\ln SA = \ln a_0 + a_1 \ln H + a_2 \ln W \qquad \text{(Eqn. 6A-11)}$$

The values for a_0, a_1, and a_2 obtained by the various authors discussed in this section are presented to follow:

Table 6A-2. Summary of Surface Area Parameter Values for the DuBois and DuBois Model

Author (year)	Number of persons	a_0	a_1	a_2
DuBois and DuBois (1916)	9	0.007184	0.725	0.425
Boyd (1935)	231	0.01787	0.500	0.4838
Gehan and George (1970)	401	0.02350	0.42246	0.51456
Haycock et al. (1978)	81	0.024265	0.3964	0.5378

The agreement between the model parameters estimated by Gehan and George (1970) and Haycock et al. (1978) is remarkable in view of the fact that Haycock et al. (1978) were unaware of the previous work. Haycock et al. (1978) used an entirely different set of subjects, and used geometric estimates of surface area rather than direct measurements.

Using the least squares procedure for the 401 observations, the following parameter estimates and their standard errors were obtained:

$$a_0 = -3.73\ (0.18),\ a_1 = 0.417\ (0.054),\ a_2 = 0.517\ (0.022)$$

The model is then:

$$SA = 0.0239\ H^{0.417}\ W^{0.517} \qquad \text{(Eqn. 6A-7)}$$

or in logarithmic form:

$$\ln SA = -3.73 + 0.417 \ln H + 0.517 \ln W \qquad \text{(Eqn. 6A-8)}$$

with a standard error about the regression of 0.00374. This model explains more than 99 percent of the total variation in surface area among the observations, and is identical to two significant figures with the model developed by Gehan and George (1970).

When natural logarithms of the measured surface areas are plotted against natural logarithms of the surface predicted by the equation, the observed surface areas are symmetrically distributed around a line of perfect fit, with only a few large percentage deviations. Only five subjects differed from the measured value by 25 percent or more. Because each of the five subjects weighed less than 13 pounds, the amount of difference was small. Eighteen estimates differed from measurements by 15 to 24 percent. Of these, 12 weighed less than 15 pounds each, 1 was overweight (5 feet 7 inches, 172 pounds), 1 was very thin (4 feet 11 inches, 78 pounds), and 4 were of average build. Since the same observer measured surface area for these 4 subjects, the possibility of some bias in measured values cannot be discounted (Gehan and George 1970).

Gehan and George (1970) also considered separate constants for different age groups: less than 5 years old, 5 years old to less than 20 years old, and greater than 20 years old. The different values for the constants are presented below:

Table 6A-1. Estimated Parameter Values for Different Age Intervals

Age group	Number of persons	a_0	a_1	a_2
All ages	401	0.02350	0.42246	0.51456
<5 years old	229	0.02667	0.38217	0.53937
≥ 5 - <20 years old	42	0.03050	0.35129	0.54375
≥ 20 years old1	30	0.01545	0.54468	0.46336

The surface areas estimated using the parameter values for all ages were compared to surface areas estimated by the values for each age group for subjects at the 3rd, 50th, and 97th percentiles of weight and height. Nearly all differences in surface area estimates were less than 0.01 square meter, and the largest difference was 0.03 m^2 for an 18-year-old at the 97th percentile. The authors concluded that there is no advantage in using separate values of a_0, a_1, and a_2 by age interval.

Gehan and George (1970) proposed another set of constants for the DuBois and DuBois model. The constants were based on a total of 401 direct measurements of surface area, height, and weight of all postnatal subjects listed in Boyd (1935). The methods used to measure these subjects were coating (163 cases), surface integration (222 cases), and triangulation (16 cases).

Gehan and George (1970) used a least-squares method to identify the values of the constants. The values of the constants chosen are those that minimize the sum of the squared percentage errors of the predicted values of surface area. This approach was used because the importance of an error of 0.1 square meter depends on the surface area of the individual. Gehan and George (1970) used the 401 observations summarized in Boyd (1935) in the least-squares method. The following estimates of the constants were obtained: $a_0 = 0.02350$, $a_1 = 0.42246$, and $a_2 = 0.51456$. Hence, their equation for predicting surface area (SA) is:

$$SA = 0.02350\ H^{0.42246}\ W^{0.51456} \qquad \text{(Eqn. 6A-3)}$$

or in logarithmic form:

$$\ln SA = -3.75080 + 0.42246 \ln H + 0.51456 \ln W \qquad \text{(Eqn. 6A-4)}$$

where:

SA = surface area in square meters;
H = height in centimeters; and
W = weight in kg.

This prediction explains more than 99 percent of the variations in surface area among the 401 individuals measured (Gehan and George, 1970).

The equation proposed by Gehan and George (1970) was determined by the U.S. EPA (1985) as the best choice for estimating total body surface area. However, the paper by Gehan and George gave insufficient information to estimate the standard error about the regression. Therefore, the 401 direct measurements of children and adults (i.e., Boyd, 1935) were reanalyzed in U.S. EPA (1985) using the formula of Dubois and Dubois (1916) and the Statistical Processing System (SPS) software package to obtain the standard error.

The Dubois and Dubois (1916) formula uses weight and height as independent variables to predict total body surface area (SA), and can be written as:

$$SA_i = a_0\ H_i^{a1}\ W_i^{a2}\ e_i \qquad \text{(Eqn. 6A-5)}$$

or in logarithmic form:

$$\ln (SA)_i = \ln a_0 + a_1 \ln H_i + a_2 \ln W_i + \ln e_i \qquad \text{(Eqn. 6A-6)}$$

where:

Sai = surface area of the i-th individual (m^2);
Hi = height of the i-th individual (cm);
Wi = weight of the i-th individual (kg);
a_0, a_1, and a_2 = parameters to be estimated; and
e_i = a random error term with mean zero and constant variance.

APPENDIX 6A

FORMULAE FOR TOTAL BODY SURFACE AREA

Most formulae for estimating surface area (SA), relate height to weight to surface area. The following formula was proposed by Gehan and George (1970):

$$SA = KW^{2/3} \qquad \text{(Eqn. 6A-1)}$$

where:

SA = surface area in square meters;
W = weight in kg; and
K = constant.

While the above equation has been criticized because human bodies have different specific gravities and because the surface area per unit volume differs for individuals with different body builds, it gives a reasonably good estimate of surface area.

A formula published in 1916 that still finds wide acceptance and use is that of DuBois and DuBois. Their model can be written:

$$SA = a_0 H^{a_1} W^{a_2} \qquad \text{(Eqn. 6A-2)}$$

where:

SA = surface area in square meters;
H = height in centimeters; and
W = weight in kg.

The values of a_0 (0.007182), a_1 (0.725), and a_2 (0.425) were estimated from a sample of only nine individuals for whom surface area was directly measured. Boyd (1935) stated that the Dubois formula was considered a reasonably adequate substitute for measuring surface area. Nomograms for determining surface area from height and mass presented in Volume I of the Geigy Scientific Tables (1981) are based on the DuBois and DuBois formula. In addition, a computerized literature search conducted for this report identified several articles written in the last 10 years in which the DuBois and DuBois formula was used to estimate body surface area.

Boyd (1935) developed new constants for the DuBois and DuBois model based on 231 direct measurements of body surface area found in the literature. These data were limited to measurements of surface area by coating methods (122 cases), surface integration (93 cases), and triangulation (16 cases). The subjects were Caucasians of normal body build for whom data on weight, height, and age (except for exact age of adults) were complete. Resulting values for the constants in the DuBois and DuBois model were $a_0 = 0.01787$, $a_1 = 0.500$, and $a_2 = 0.4838$. Boyd also developed a formula based exclusively on weight, which was inferior to the DuBois and DuBois formula based on height and weight.

APPENDIX 6A

FORMULAE FOR TOTAL BODY SURFACE AREA

Table 7-7. Weight in Kilograms for Females 6 Months-19 Years of Age--Number Examined, Mean, Standard Deviation, and Selected Percentiles, by Sex and Age. United States, 1976-1980[a]

Age	Number of Persons Examined	Mean (kg)	Standard Deviation	Percentile 5th	10th	15th	25th	50th	75th	85th	90th	95th
6-11 months	177	8.8	1.2	6.6	7.3	7.5	7.9	8.9	9.4	10.1	10.4	10.9
1 years	336	10.8	1.4	8.8	9.1	9.4	9.9	10.7	11.7	12.4	12.7	13.4
2 years	336	13.0	1.5	10.8	11.2	11.6	12.0	12.7	13.8	14.5	14.9	15.9
3 years	366	14.9	2.1	11.7	12.3	12.9	13.4	14.7	16.1	17.0	17.4	18.4
4 years	396	17.0	2.4	13.7	14.3	14.5	15.2	16.7	18.4	19.3	20.2	21.1
5 years	364	19.6	3.3	15.3	16.1	16.7	17.2	19.0	21.2	22.8	24.7	26.6
6 years	135	22.1	4.0	17.0	17.8	18.6	19.3	21.3	23.8	26.6	28.9	29.6
7 years	157	24.7	5.0	19.2	19.5	19.8	21.4	23.8	27.1	28.7	30.3	34.0
8 years	123	27.9	5.7	21.4	22.3	23.3	24.4	27.5	30.2	31.3	33.2	36.5
9 years	149	31.9	8.4	22.9	25.0	25.8	27.0	29.7	33.6	39.3	43.3	48.4
10 years	136	36.1	8.0	25.7	27.5	29.0	31.0	34.5	39.5	44.2	45.8	49.6
11 years	140	41.8	10.9	29.8	30.3	31.3	33.9	40.3	45.8	51.0	56.6	60.0
12 years	147	46.4	10.1	32.3	35.0	36.7	39.1	45.4	52.6	58.0	60.5	64.3
13 years	162	50.9	11.8	35.4	39.0	40.3	44.1	49.0	55.2	60.9	66.4	76.3
14 years	178	54.8	11.1	40.3	42.8	43.7	47.4	53.1	60.3	65.7	67.6	75.2
15 years	145	55.1	9.8	44.0	45.1	46.5	48.2	53.3	59.6	62.2	65.5	76.6
16 years	170	58.1	10.1	44.1	47.3	48.9	51.3	55.6	62.5	68.9	73.3	76.8
17 years	134	59.6	11.4	44.5	48.9	50.5	52.2	58.4	63.4	68.4	71.6	81.8
18 years	170	59.0	11.1	45.3	49.5	50.8	52.8	56.4	63.0	66.0	70.1	78.0
19 years	158	60.2	11.0	48.5	49.7	51.7	53.9	57.1	64.4	70.7	74.8	78.1

Note: 1 kg = 2.2046 pounds.
[a] Includes clothing weight, estimated as ranging from 0.09 to 0.28 kilogram.

Source: National Center for Health Statistics, 1987.

Table 7 6. Weight in Kilograms for Males 6 Months-19 Years of Age–Number Examined, Mean, Standard Deviation, and Selected Percentiles, by Sex and Age: United States, 1976-1980[a]

Age	Number of Persons Examined	Mean (kg)	Standard Deviation	Percentile 5th	10th	15th	25th	50th	75th	85th	90th	95th
6-11 months	179	9.4	1.3	7.5	7.6	8 2	8 6	9.4	10.1	10.7	10.9	11.4
1 years	370	11.8	1.9	9 6	10 0	10 3	10 8	11.7	12 6	13.1	13 6	14.4
2 years	375	13 6	1.7	11.1	11.6	11 8	12 6	13.5	14 5	15 2	15 8	16 5
3 years	418	15.7	2 0	12.9	13.5	13.9	14.4	15.4	16 8	17.4	17.9	19 1
4 years	404	17.8	2.5	14.1	15 0	15.3	16 0	17.6	19 0	19.9	20.9	22 2
5 years	397	19 8	3 0	16 0	16 8	17.1	17.7	19.4	21 3	22.9	23.7	25.4
6 years	133	23 0	4 0	18 6	19 2	19.8	20.3	22 0	24 1	26.4	28 3	30.1
7 years	148	25.1	3.9	19.7	20 8	21.2	22.2	24 8	26 9	28 2	29 6	33.9
8 years	147	28 2	6 2	20.4	22.7	23.6	24 6	27.5	29.9	33 0	35 5	39.1
9 years	145	31.1	6.3	24 0	25 6	26 0	27.1	30 2	33 0	35.4	38 6	43.1
10 years	157	36.4	7.7	27.2	28 2	29 6	31.4	34 8	39 2	43.5	46 3	53.4
11 years	155	40 3	10 1	26 8	28 8	31 8	33.5	37.3	46.4	52 0	57.0	61 0
12 years	145	44 2	10.1	30.7	32.5	35.4	37.8	42 5	48 8	52 6	58.9	67.5
13 years	173	49.9	12.3	35.4	37 0	38 3	40.1	48.4	56 3	59 8	64 2	69.9
14 years	186	57.1	11.0	41 0	44 5	46.4	49 8	56 4	63.3	66.1	68.9	77 0
15 years	184	61.0	11 0	46 2	49.1	50 6	54.2	60.1	64.9	68.7	72 8	81.3
16 years	178	67.1	12.4	51.4	54 3	56.1	57.6	64.4	73 6	78.1	82 2	91.2
17 years	173	66.7	11.5	50.7	53.4	54 8	58 8	65 8	72 0	76 8	82 3	88 9
18 years	164	71.1	12.7	54 1	56 6	60 3	61.9	70 4	76 6	80 0	83.5	95 3
19 years	148	71.7	11.6	55.9	57.9	60 5	63.8	69.5	77.9	84.3	86 8	92.1

Note: 1 kg = 2 2046 pounds.
[a] Includes clothing weight, estimated as ranging from 0 09 to 0 28 kilogram.

Source: National Center for Health Statistics, 1987.

Table 7-5. Weight in Kilograms for Females 18-74 Years of Age--Number Examined, Mean, Standard Deviation, and Selected Percentiles, by Race and Age: United States, 1976-1980[a]

Race and Age	Number of Persons Examined	Mean (kg)	Standard Deviation	Percentile 5th	10th	15th	25th	50th	75th	85th	90th	95th
All races[b]												
18-74 years	6,588	65.4	14.6	47.7	50.3	52.2	55.4	62.4	72.1	79.2	84.4	93.1
18-24 years	1,066	60.6	11.9	46.6	49.1	50.6	53.2	58.0	65.0	70.4	75.3	82.9
25-34 years	1,170	64.2	15.0	47.4	49.6	51.4	54.3	60.9	69.6	78.4	84.1	93.5
35-44 years	844	67.1	15.2	49.2	52.0	53.3	56.9	63.4	73.9	81.7	87.5	98.9
45-54 years	763	68.0	15.3	48.5	51.3	53.3	57.3	65.5	75.7	82.1	87.6	96.0
55-64 years	1,329	67.9	14.7	48.6	51.3	54.1	57.3	65.2	75.3	82.3	87.5	95.1
65-74 years	1,416	66.6	13.8	47.1	50.8	53.2	57.4	64.8	73.8	79.8	84.4	91.3
White												
18-74 years	5,686	64.8	14.1	47.7	50.3	52.2	55.2	62.1	71.1	77.9	83.3	91.5
18-24 years	892	60.4	11.6	47.3	49.5	50.8	53.3	57.9	64.8	69.7	74.3	82.4
25-34 years	1,000	63.6	14.5	47.3	49.5	51.3	54.0	60.6	68.9	76.3	81.5	89.7
35-44 years	726	66.1	14.5	49.3	51.8	52.9	56.3	62.4	71.9	79.7	85.8	94.9
45-54 years	617	67.3	14.4	48.6	51.3	53.4	57.0	65.0	74.8	81.1	85.6	94.5
55-64 years	1,176	67.2	14.4	48.5	50.7	53.7	57.1	64.7	74.5	81.8	86.2	92.8
65-74 years	1,245	66.2	13.7	47.2	50.7	52.9	57.2	64.3	72.9	79.2	84.3	91.2
Black												
18-74 years	782	71.2	17.3	48.8	51.6	55.1	59.1	67.8	80.6	87.4	94.9	105.4
18-24 years	147	63.1	13.9	46.2	49.0	50.6	53.8	60.4	70.0	75.8	79.1	89.3
25-34 years	145	69.3	16.7	48.3	50.8	53.1	57.8	65.3	80.2	87.1	91.5	102.7
35-44 years	103	75.3	18.4	50.7	55.2	57.2	63.0	70.2	85.2	95.3	103.5	113.1
45-54 years	100	77.7	18.8	55.1	60.3	60.8	64.5	74.3	83.6	94.5	98.2	117.5
55-64 years	135	75.8	16.4	54.2	55.2	57.6	65.4	74.6	83.4	91.9	95.5	108.5
65-74 years	152	72.4	13.6	52.9	56.4	60.3	64.0	70.0	82.2	84.4	86.5	98.1

Note: 1 kg = 2.2046 pounds.
[a] Includes clothing weight, estimated as ranging from 0.09 to 0.28 kilogram.
[b] Includes all other races not shown as separate categories.

Source: National Center for Health Statistics, 1987.

Table 7-4. Weight in Kilograms for Males 18-74 Years of Age--Number Examined, Mean, Standard Deviation, and Selected Percentiles, by Race and Age: United States, 1976-1980[a]

Race and Age	Number of Persons Examined	Mean (kg)	Standard Deviation	Percentile 5th	10th	15th	25th	50th	75th	85th	90th	95th
All races[b]												
18-74 years	5,916	78.1	13.5	58.6	62.3	64.9	68.7	76.9	85.6	91.3	95.7	102.7
18-24 years	958	73.8	12.7	56.8	60.4	61.9	64.8	72.0	80.3	85.1	90.4	99.5
25-34 years	1,067	78.7	13.7	59.5	62.9	65.4	69.3	77.5	85.6	91.1	95.1	102.7
35-44 years	745	80.9	13.4	59.7	65.1	67.7	72.1	79.9	88.1	94.8	98.8	104.3
45-54 years	690	80.9	13.6	50.8	65.2	67.2	71.7	79.0	89.4	94.5	99.5	105.3
55-64 years	1,227	78.8	12.8	59.9	63.8	66.4	70.2	77.7	85.6	90.5	94.7	102.3
65-74 years	1,199	74.8	12.8	54.4	58.5	61.2	66.1	74.2	82.7	87.9	91.2	96.6
White												
18-74 years	5,148	78.5	13.1	59.3	62.8	65.5	69.4	77.3	85.6	91.4	95.5	102.3
18-24 years	816	74.2	12.8	56.8	60.5	62.0	65.0	72.4	80.6	85.5	91.0	100.0
25-34 years	901	79.0	13.1	59.9	63.7	65.9	69.8	78.0	85.6	91.3	95.3	102.7
35-44 years	653	81.4	12.8	62.3	66.6	68.8	72.9	80.1	88.2	91.6	98.7	104.1
45-54 years	617	81.0	13.4	62.0	66.1	67.3	71.9	79.0	89.4	94.2	99.0	104.5
55-64 years	1,086	78.9	12.4	60.5	64.5	66.6	70.6	78.2	85.6	90.4	94.5	101.7
65-74 years	1,045	75.4	12.4	55.5	59.5	62.5	67.0	74.7	83.0	87.9	91.2	96.0
Black												
18-74 years	649	77.9	15.2	58.0	61.1	63.6	67.2	75.3	85.4	92.9	98.3	105.4
18-24 years	121	72.2	12.0	58.3	60.9	62.3	64.9	70.8	77.1	81.8	83.7	93.6
25-34 years	139	78.2	16.3	58.7	63.4	64.9	68.4	75.3	84.4	90.6	92.2	106.3
35-44 years	70	82.5	15.4	*[c]	61.7	65.2	69.7	83.1	94.8	100.4	104.2	*
45-54 years	62	82.4	14.5	*	64.7	67.0	73.2	81.8	93.0	100.0	102.5	*
55-64 years	129	78.6	14.7	56.8	61.4	64.3	68.0	77.0	86.5	93.8	98.6	104.7
65-74 years	128	73.3	15.3	52.5	56.7	58.0	61.0	71.2	81.1	90.8	97.3	105.1

Note: 1 kg = 2.2046 pounds.
[a] Includes clothing weight, estimated as ranging from 0.09 to 0.28 kilogram.
[b] Includes all other races not shown as separate categories.
[c] Data not available.

Source: National Center for Health Statistics, 1987.

that 15 years old. However, this study does provide body weight data for infants less than 6 months old.

NCHS (1987) - Anthropometric Reference Data and Prevalence of Overweight, United States, 1976-80 - Statistics on anthropometric measurements, including body weight, for the U.S. population were collected by NCHS through the second National Health and Nutrition Examination Survey (NHANES II). NHANES II was conducted on a nationwide probability sample of approximately 28,000 persons, aged 6 months to 74 years, from the civilian, non-institutionalized population of the United States. Of the 28,000 persons, 20,322 were interviewed and examined, resulting in a response rate of 73.1 percent. The survey began in February 1976 and was completed in February 1980. The sample was selected so that certain subgroups thought to be at high risk of malnutrition (persons with low incomes, preschool children, and the elderly) were oversampled. The estimates were weighted to reflect national population estimates. The weighting was accomplished by inflating examination results for each subject by the reciprocal of selection probabilities adjusted to account for those who were not examined, and post stratifying by race, age, and sex (NCHS, 1987).

The NHANES II collected standard body measurements of sample subjects, including height and weight, that were made at various times of the day and in different seasons of the year. This technique was used because one's weight may vary between winter and summer and may fluctuate with recency of food and water intake and other daily activities (NCHS, 1987). Mean body weights of adults, by age, and their standard deviations are presented in Table 7-2 for men, women, and both sexes combined. Mean body weights and standard deviations for children, ages 6 months to 19 years, are presented in Table 7-3 for boys, girls, and boys and girls combined. Percentile distributions of the body weights of adults by age and race for males are presented in Table 7-4, and for females in Table 7-5. Data for children by age are presented in Table 7-6 for males, and for females in Table 7-7.

Results shown in Tables 7-4 and 7-5 indicate that the mean weight for adult males is 78.1 kg and for adult females, 65.4 kg. It also shows that the mean weight for White males (78.5 kg) is greater than for Black males (77.9 kg). Additionally, mean weights are greater for Black females (71.2 kg) than for White females (64.8 kg). From Table 7-3, the mean body weights for girls and boys are approximately the same from ages 6 months to 14 years. Starting at years 15-19, the difference in mean body weight ranges from 6 to 11 kg.

Table 7-2 Body Weights of Adults* (kilograms)

Age (years)	Men		Women		Men and Women
	Mean (kg)	Std. Dev	Mean (kg)	Std. Dev	Mean (kg)
18 < 25	73.8	12.7	60.6	11.9	67.2
25 < 35	78.7	13.7	64.2	15.0	71.5
35 < 45	80.9	13.4	67.1	15.2	74.0
45 < 55	80.9	13.6	68.0	15.3	74.5
55 < 65	78.8	12.8	67.9	14.7	73.4
65 < 75	74.8	12.8	66.6	13.8	70.7
18 < 75	78.1	13.5	65.4	14.6	71.8

Note: 1 kg = 2.2046 pounds.
* Includes clothing weight, estimated as ranging from 0.09 to 0.28 kilogram.
Source: Adapted from National Center for Health Statistics (NCHS), 1987.

Table 7-3 Body Weights of Children* (kilograms)

Age	Boys		Girls		Boys and Girls
	Mean (kg)	Std Dev	Mean (kg)	Std. Dev	Mean (kg)
6-11 months	9.4	1.3	8.8	1.2	9.1
1 year	11.8	1.9	10.8	1.4	11.3
2 years	13.6	1.7	13.0	1.5	13.3
3 years	15.7	2.0	14.9	2.1	15.3
4 years	17.8	2.5	17.0	2.4	17.4
5 years	19.8	3.0	19.6	3.3	19.7
6 years	23.0	4.0	22.1	4.0	22.6
7 years	25.1	3.9	24.7	5.0	24.9
8 years	28.2	6.2	27.9	5.7	28.1
9 years	31.1	6.3	31.9	8.4	31.5
10 years	36.4	7.7	36.1	8.0	36.3
11 years	40.3	10.1	41.8	10.9	41.1
12 years	44.2	10.1	46.4	10.1	45.3
13 years	49.9	12.3	50.9	11.8	50.4
14 years	57.1	11.0	54.8	11.1	56.0
15 years	61.0	11.0	55.1	9.8	58.1
16 years	67.1	12.4	58.1	10.1	62.6
17 years	66.7	11.5	59.6	11.4	63.2
18 years	71.1	12.7	59.0	11.1	65.1
19 years	71.7	11.6	60.2	11.0	66.0

Note: 1 kg = 2.2046 pounds.
* Includes clothing weight, estimated as ranging from 0.09 to 0.28 kilogram.
Source: Adapted from National Center for Health Statistics (NCHS), 1987.

7.2 RELEVANT BODY WEIGHT STUDIES

Brainard and Burmaster (1992) - Bivariate Distributions for Height and Weight of Men and Women in the United States - Brainard and Burmaster (1992) examined data on the height and weight of adults published by the U.S. Public Health Service and fit bivariate distributions to the tabulated values for men and women, separately.

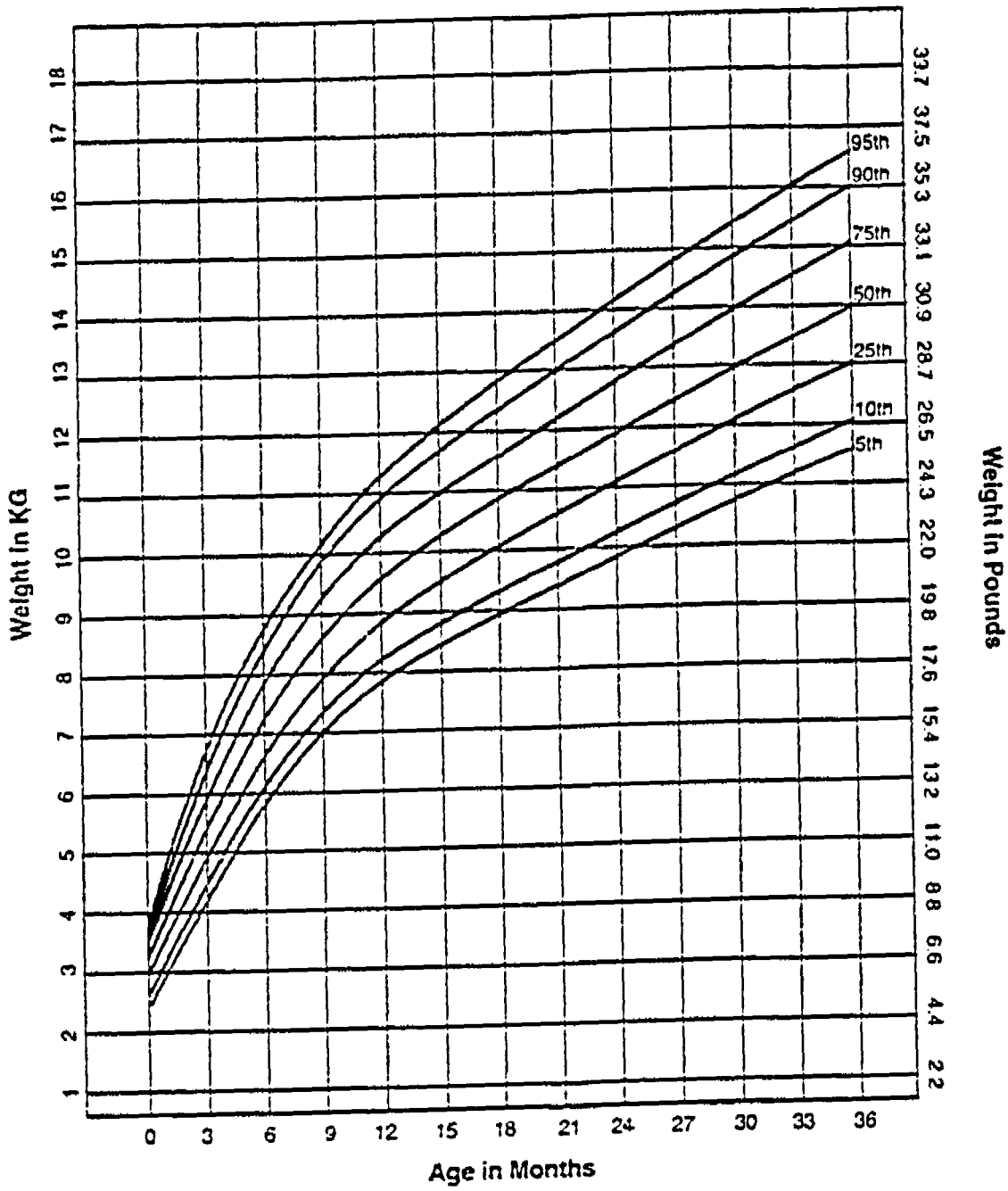


Figure 7-2. Weight by Age Percentiles for Girls Aged Birth-36 Months

Source: Hamill et al., 1979

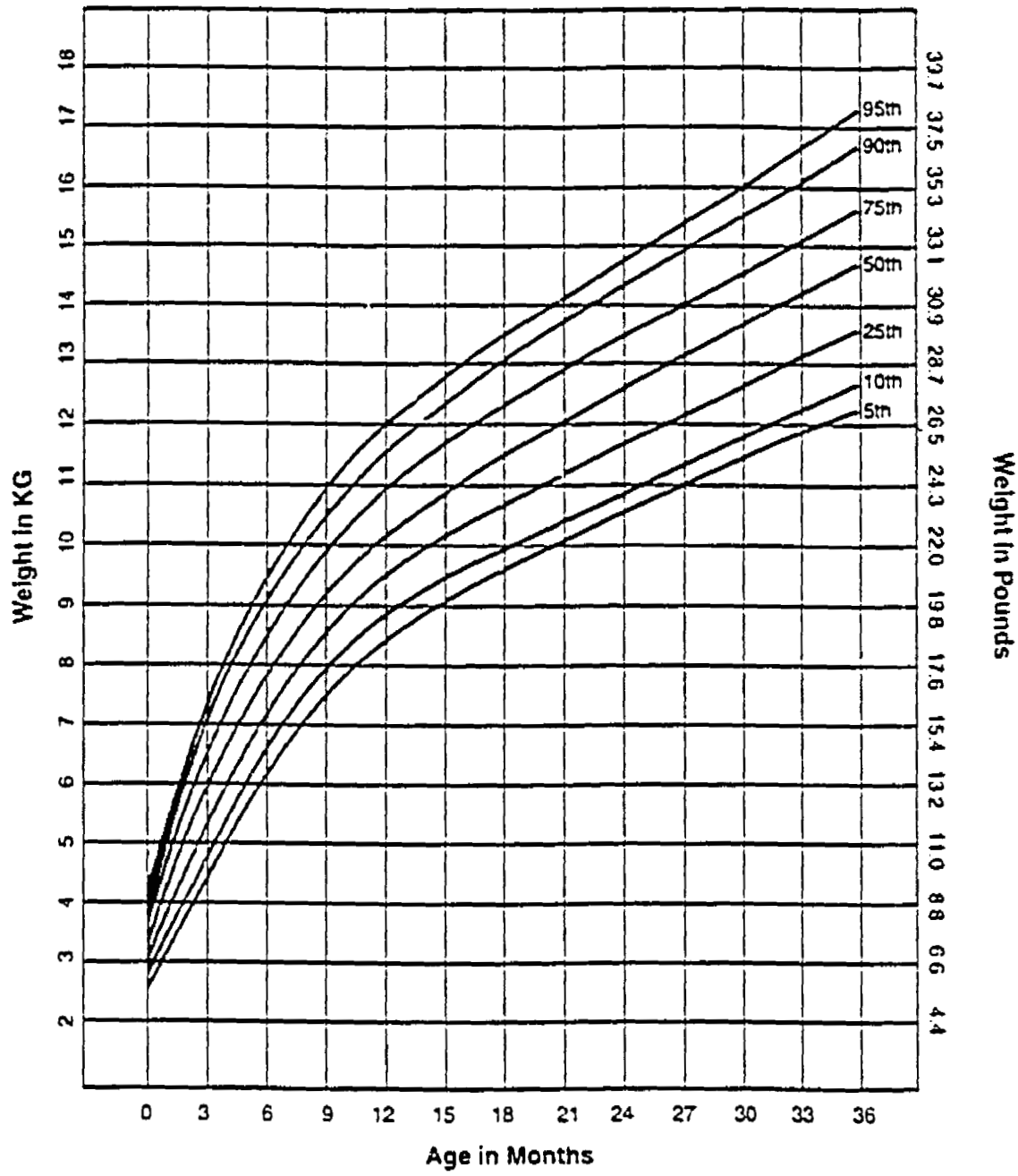


Figure 7-1. Weight by Age Percentiles for Boys Aged Birth-36 Months
Source: Hamill et al., 1979.

7. BODY WEIGHT STUDIES

There are several physiological factors needed to calculate potential exposures. These include skin surface area (see Volume I, Section 6), inhalation rate (see Volume I, Section 5) life expectancy (see Volume I, Section 8), and body weight. The average daily dose is typically normalized to the average body weight of the exposed population. If exposure occurs only during childhood years, the average child body weight during the exposure period should be used to estimate risk (U.S. EPA, 1989). Conversely, if adult exposures are being evaluated, an adult body weight value should be used.

The purpose of this section is to describe published studies on body weight for the general U.S. population. The studies have been classified as either key or relevant studies, based on the criteria described in Volume I, Section 1.3.1. Recommended values are based on the results of key studies, but relevant studies are also presented to provide the reader with added perspective on the current state of knowledge pertaining to body weight.

7.1. KEY BODY WEIGHT STUDY

Hamill et al. (1979) - Physical Growth: National Center for Health Statistics Percentiles - A National Center for Health Statistics (NCHS) Task Force that included academic investigators and representatives from CDC Nutrition Surveillance Program selected, collated, integrated, and defined appropriate data sets to generate growth curves for the age interval: birth to 36 months developed (Hamill et al., 1979). The percentile curves were for assessing the physical growth of children in the U.S. They are based on accurate measurements made on large nationally representative samples of children (Hamill et al., 1979). Smoothed percentile curves were derived for body weight by age (Hamill et al., 1979). Curves were developed for boys and for girls. The data used to construct the curves were provided by the Fels Research Institute, Yellow Springs, Ohio. These data were from an ongoing longitudinal study where anthromopetric data from direct measurements are collected regularly from participants (~1,000) in various areas of the U.S. The NCHS used advanced statistical and computer technology to generate the growth curves. Table 7-1 presents the percentiles of weight by sex and age. Figures 7-1 and 7-2 present weight by age percentiles for boys and for girls aged birth to 36 months, respectively. Limitations of this study are that mean body weight values were not reported and the data are more

Table 7-1. Smoothed Percentiles of Weight (in kg) by Sex and Age: Statistics from NCHS and Data from Fels Research Institute, Birth to 36 Months

	Smoothed* Percentile						
	5th	10th	25th	50th	75th	90th	95th
Sex and Age	Weight in Kilograms						
Male							
Birth	2.54	2.78	3.00	3.27	3.64	3.82	4.15
1 Month	3.16	3.43	3.82	4.29	4.75	5.14	5.38
3 Months	4.43	4.78	5.32	5.98	6.56	7.14	7.37
6 Months	6.20	6.61	7.20	7.85	8.49	9.10	9.46
9 Months	7.52	7.95	8.56	9.18	9.88	10.49	10.93
12 Months	8.43	8.84	9.49	10.15	10.91	11.54	11.99
18 Months	9.59	9.92	10.67	11.47	12.31	13.05	13.44
24 Months	10.54	10.85	11.65	12.59	13.44	14.29	14.70
30 Months	11.44	11.80	12.63	13.67	14.51	15.47	15.97
36 Months	12.26	12.69	13.58	14.69	15.59	16.66	17.28
Female							
Birth	2.36	2.58	2.93	3.23	3.52	3.64	3.81
1 Month	2.97	3.22	3.59	3.98	4.36	4.65	4.92
3 Months	4.18	4.47	4.88	5.40	5.90	6.39	6.74
6 Months	5.79	6.12	6.60	7.21	7.83	8.38	8.73
9 Months	7.00	7.34	7.89	8.56	9.24	9.83	10.17
12 Months	7.84	8.19	8.81	9.53	10.23	10.87	11.24
18 Months	8.92	9.30	10.04	10.82	11.55	12.30	12.76
24 Months	9.87	10.26	11.10	11.90	12.74	13.57	14.08
30 Months	10.78	11.21	12.11	12.93	13.93	14.81	15.35
36 Months	11.60	12.07	12.99	13.93	15.03	15.97	16.54

* Smoothed by cubic-spline approximation.
Source: Hamill et al., 1979

Table 8-3. Confidence in Lifetime Expectancy Recommendations

Considerations	Rationale	Rating
Study Elements		
• Level of peer review	Data are published and have received extensive peer review.	High
• Accessibility	The study was widely available to the public (Census data).	High
• Reproducibility	Results can be reproduced by analyzing Census data.	High
• Focus on factor of interest	Statistical data on life expectancy were published in this study.	High
• Data pertinent to US	The study focused on the U.S. population.	High
• Primary data	Primary data were analyzed.	High
• Currency	The study was published in 1995 and discusses life expectancy trends from 1970 to 1993. The study has also made projections for 1995 until the year 2010	High
• Adequacy of data collection period	The data analyzed were collected over a period of years.	High
• Validity of approach	Census data is collected and analyzed over a period of years.	High
• Study size	This study was based on U.S. Census data, thus the population study size is expected to be greater than 100.	High
• Representativeness of the population	The data are representative of the U.S. population.	High
• Characterization of variability	Data were averaged by gender and race but only for Blacks and Whites; no other nationalities were represented within the section.	Medium
• Lack of bias in study design (High rating is desirable)	There are no apparent biases.	High
• Measurement error	Measurement error may be attributed to portions of the population that avoid or provide misleading information on census surveys	Medium
Other Elements		
• Number of studies	Data presented in the section are from the U.S. Bureau of the Census publication.	Low
• Agreement between researchers	Recommendation was based on only one study, but it is widely accepted.	High
Overall Rating		**HIGH**

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Table 8-2. Expectation of Life by Race, Sex, and Age: 1992 (continued)

Age in 1990 (years)	Expectation of Life in Years				
		White		Black	
	Total	Male	Female	Male	Female
50	29.3	27.1	31.9	23.0	28.5
51	28.5	26.3	31.0	22.3	27.7
52	27.6	25.4	30.1	21.5	26.8
53	26.8	24.6	29.2	20.8	26.0
54	25.9	23.7	28.3	20.1	25.3
55	25.1	22.9	27.5	19.5	24.5
56	24.3	22.1	26.6	18.8	23.7
57	23.5	21.3	25.7	18.2	23.0
58	22.7	20.6	24.9	17.6	22.2
59	21.9	19.8	24.1	16.9	21.5
60	21.1	19.1	23.2	16.3	20.8
61	20.4	18.3	22.4	15.8	20.1
62	19.7	17.6	21.6	15.2	19.4
63	18.9	16.9	20.8	14.6	18.7
64	18.2	16.2	20.0	14.1	18.0
65	17.5	15.5	19.3	13.5	17.4
70	14.2	12.4	15.6	11.0	14.3
75	11.2	9.6	12.2	8.9	11.4
80	8.5	7.2	9.2	6.8	8.6
85 and over	6.2	5.3	6.6	5.1	6.3

Source: U.S. Bureau of Census, 1995.

Table 8-2. Expectation of Life by Race, Sex, and Age: 1992

Age in 1990 (years)	Expectation of Life in Years				
	White			Black	
	Total	Male	Female	Male	Female
At birth	75.8	73.2	79.8	65.0	73.9
1	75.4	72.8	79.3	65.2	74.1
2	74.5	71.8	78.3	64.3	73.1
3	73.5	70.9	77.3	63.4	72.2
4	72.5	69.9	76.3	62.4	71.2
5	71.6	68.9	75.4	61.4	70.3
6	70.6	67.9	74.4	60.5	69.3
7	69.6	66.9	73.4	59.5	68.3
8	68.6	65.9	72.4	58.5	67.3
9	67.6	65.0	71.4	57.5	66.3
10	66.6	64.0	70.4	56.5	65.4
11	65.6	63.0	69.4	55.5	64.4
12	64.6	62.0	68.4	54.6	63.4
13	63.7	61.0	67.4	53.6	62.4
14	62.7	60.0	66.5	52.6	61.4
15	61.7	59.1	65.5	51.7	60.4
16	60.7	58.1	64.5	50.7	59.5
17	59.8	57.2	63.5	49.8	58.5
18	58.8	56.2	62.5	48.9	57.5
19	57.9	55.3	61.6	48.1	56.6
20	56.9	54.3	60.6	47.2	55.6
21	56.0	53.4	59.6	46.3	54.6
22	55.1	52.5	58.7	45.5	53.7
23	54.1	51.6	57.7	44.6	52.7
24	53.2	50.6	56.7	43.8	51.8
25	52.2	49.7	55.7	42.9	50.8
26	51.3	48.8	54.8	42.1	49.9
27	50.4	47.8	53.8	41.2	48.9
28	49.4	46.9	52.8	40.4	48.0
29	48.5	46.0	51.8	39.5	47.1
30	47.5	45.1	50.9	38.7	46.1
31	46.6	44.1	49.9	37.8	45.2
32	45.7	43.2	48.9	37.0	44.3
33	44.7	42.3	48.0	36.2	43.4
34	43.8	41.4	47.0	35.3	42.4
35	42.9	40.5	46.0	34.5	41.5
36	42.0	39.6	45.1	33.7	40.6
37	41.0	38.7	44.1	32.9	39.7
38	40.1	37.8	43.2	32.1	38.8
39	39.2	36.9	42.2	31.3	37.9
40	38.3	36.0	41.2	30.5	37.1
41	37.4	35.1	40.3	29.7	36.2
42	36.5	34.2	39.3	28.9	35.3
43	35.6	33.3	38.4	28.2	34.4
44	34.7	32.4	37.5	27.4	33.6
45	33.8	31.5	36.5	26.7	32.7
46	32.9	30.6	35.6	25.9	31.9
47	32.0	29.7	34.7	25.2	31.0
48	31.1	28.8	33.7	24.4	30.2
49	30.2	28.0	32.8	23.7	29.3

Table 8-1. Expectation of Life at Birth, 1970 to 1993, and Projections, 1995 to 2010 (years)[a]

YEAR		TOTAL			WHITE			BLACK AND OTHER[b]			BLACK		
		Total	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female
1970		70.8	67.1	74.7	71.7	68.0	75.6	65.3	61.3	69.4	64.1	60.0	68.3
1975		72.6	68.8	76.6	73.4	69.5	77.3	68.0	63.7	72.4	66.8	62.4	71.3
1980		73.7	70.0	77.4	74.4	70.7	78.1	69.5	65.3	73.6	68.1	63.8	72.5
1981		74.1	70.4	77.8	74.8	71.1	78.4	70.3	66.2	74.4	68.9	64.5	73.2
1982		74.5	70.8	78.1	75.1	71.5	78.7	70.9	66.8	74.9	69.4	65.1	73.6
1983		74.6	71.0	78.1	75.2	71.6	78.7	70.9	67.0	74.7	69.4	65.2	73.5
1984		74.7	71.1	78.2	75.3	71.8	78.7	71.1	67.2	74.9	69.5	65.3	73.6
1985		74.7	71.1	78.2	75.3	71.8	78.7	71.0	67.0	74.8	69.3	65.0	73.4
1986		74.7	71.2	78.2	75.4	71.9	78.8	70.9	66.8	74.9	69.1	64.8	73.4
1987		74.9	71.4	78.3	75.6	72.1	78.9	71.0	66.9	75.0	69.1	64.7	73.4
1988		74.9	71.4	78.3	75.6	72.2	78.9	70.8	66.7	74.8	68.9	64.4	73.2
1989		75.1	71.7	78.5	75.9	72.5	79.2	70.9	66.7	74.9	68.8	64.3	73.3
1990		75.4	71.8	78.8	76.1	72.7	79.4	71.2	67.0	75.2	69.1	64.5	73.6
1991		75.5	71.0	78.9	76.3	72.9	79.6	71.5	67.3	75.5	69.3	64.6	73.8
1992		75.8	72.3	79.1	76.5	73.2	79.8	71.8	67.7	75.7	69.6	65.0	73.9
1993		75.5	72.1	78.9	76.3	73.0	79.5	71.5	67.4	75.5	69.3	64.7	73.7
Projections[c]	1995	76.3	72.8	79.7	77.0	73.7	80.3	72.5	68.2	76.8	70.3	65.8	74.8
	2000	76.7	73.2	80.2	77.6	74.3	80.9	72.9	68.3	77.5	70.2	65.3	75.1
	2005	77.3	73.8	80.7	78.2	74.9	81.4	73.6	69.1	78.1	70.7	65.9	75.5
	2010	77.9	74.5	81.3	78.8	75.6	81.0	74.3	69.9	78.7	71.3	66.5	76.0

a Excludes deaths of nonresidents of the United States.
b Racial descriptions were not provided in the data source
c Based on middle mortality assumptions; for details, see U.S. Bureau of the Census, Current Population Reports, Series P-25, No. 1104.

Source: Bureau of the Census, 1995.

8. LIFETIME

The length of an individual's life is an important factor to consider when evaluating cancer risk because the dose estimate is averaged over an individual's lifetime. Since the averaging time is found in the denominator of the dose equation, a shorter lifetime would result in a higher potential risk estimate, and conversely, a longer life expectancy would produce a lower potential risk estimate.

8.1. KEY STUDY ON LIFETIME

Statistical data on life expectancy are published annually by the U.S. Department of Commerce in the publication: "Statistical Abstract of the United States." The latest year for which statistics are available is 1993. Available data on life expectancies for various subpopulations born in the years 1970 to 1993 are presented in Table 8-1. Data for 1993 show that the life expectancy for an average person born in the United States in 1993 is 75.5 years (U.S. Bureau of the Census, 1995). The table shows that the overall life expectancy has averaged approximately 75 years since 1982. The average life expectancy for males in 1993 was 72.1 years, and 78.9 years for females. The data consistently show an approximate 7 years difference in life expectancy for males and females from 1970 to present. Table 8-1 also indicates that life expectancy for white males (73.0 years) is consistently longer than for Black males (64.7 years). Additionally, it indicates that life expectancy for White females (79.5 years) is longer than for Black females (73.7), a difference of almost 6 years. Table 8-2 presents data for expectation of life for persons who were at a specific age in year 1990. These data are available by age, gender, and race and may be useful for deriving exposure estimates based on the age of a specific subpopulation. The data show that expectation of life is longer for females and for Whites.

8.2. RECOMMENDATIONS

Current data suggest that 75 years would be an appropriate value to reflect the average life expectancy of the general population and is the recommended value. If gender is a factor considered in the assessment, note that the average life expectancy value for females is higher than for males. It is recommended that the assessor use the appropriate value of 72.1 years for males or 78.9 years for females. If race is a consideration in assessing exposure for male individuals, note that the life expectancy is about 8 years longer for Whites than for Blacks. It is recommended that the assessor use the values of 73 years and 64.7 years for White males and Black males, respectively. Table 8-3 presents the confidence rating for life expectancy recommendations.

This recommended value is different than the 70 years commonly assumed for the general population in EPA risk assessments. Assessors are encouraged to use values which most accurately reflect the exposed population. When using values other than 70 years, however, the assessors should consider if the dose estimate will be used to estimate risk by combining with a dose-response relationship which was derived assuming a lifetime of 70 years. If such an inconsistency exists, the assessor should adjust the dose-response relationship by multiplying by (lifetime/70). The Integrated Risk Information System (IRIS) does not use a 70 year lifetime assumption in the derivation of RfCs and RfDs, but does make this assumption in the derivation of some cancer slope factors or unit risks.

8.3. REFERENCES FOR CHAPTER 8

U.S. Bureau of the Census. (1995) Statistical abstracts of the United States.

Table 7-12. Confidence in Body Weight Recommendations

Considerations	Rationale	Rating
Study Elements		
• Level of peer review	NHANES II was the major source of data for NCHS (1987). This is a published study which received a high level of peer review. The Hamill et al. (1979) is a peer reviewed journal publication.	High
• Accessibility	Both studies are available to the public.	High
• Reproducibility	Results can be reproduced by analyzing NHANES II data and the Fels Research Institute data.	High
• Focus on factor of interest	The studies focused on body weight, the exposure factor of interest.	High
• Data pertinent to US	The data represent the U.S. population.	High
• Primary data	The primary data were generated from NHANES II data and Fels studies, thus these data are secondary.	Medium
• Currency	The data were collected between 1976-1980.	Low
• Adequacy of data collection period	The NHANES II study included data collected over a period of 4 years. Body weight measurements were taken at various times of the day and at different seasons of the year.	High
• Validity of approach	Direct body weights were measured for both studies. For NHANES II, subgroups at risk for malnutrition were over-sampled. Weighting was accomplished by inflating examination results for those not examined and were stratified by race, age, and sex. The Fels data are from an ongoing longitudinal study where the data are collected regularly.	High
• Study size	The sample size consisted of 28,000 persons for NHANES II. Author noted in Hamill et al. (1979) that the data set was large.	High
• Representativeness of the population	Data collected focused on the U.S. population for both studies.	High
• Characterization of variability	Both studies characterized variability regarding age and sex. Additionally NHANES II characterized race (for Blacks, Whites and total populations) and sampled persons with low income.	High
• Lack of bias in study design (high rating is desirable)	There are no apparent biases in the study designs for NHANES II. The study design for collecting the Fels data was not provided.	Medium-High
• Measurement error	For NHANES II, measurement error should be low since body weights were performed in a mobile examination center using standardized procedures and equipment. Also, measurements were taken at various times of the day to account for weight fluctuations as a result of recent food or water intake. The authors of Hamill et al. (1979) report that study data are based on accurate direct measurements from an ongoing longitudinal study.	High
Other Elements		
• Number of studies	There are two studies.	Low
• Agreement between researchers	There is consistency among the two studies.	High
Overall Rating		**High**

Table 7-10. Summary of Body Weight Studies

Study	Number of Subjects	Population	Comments
KEY STUDIES			
Hamill et al. (1979)	~1,000	U.S. general population	Authors noted that data are accurate measurements from a large nationally representative sample of children.
NCHS, 1987 (NHANES II)	20,322	U.S. general population	Based on civilian non-institutionalized population aged 6 months to 74 years. Response rate was 73.1 percent.
RELEVANT STUDIES			
Brainard and Burmaster, 1992	12,501 (5,916 men and 6,588 women)	U.S. general population	Used data from NHANES II to fit bivariate distributions to women and men age 18 to 74 years.
Burmaster et al., 1994	8,458 (4,079 females and 4,379 males)	U.S. general population	Used data from NHANES II to develop fitted distributions for children aged 6 to 20 years old. Adjusted for non-response by age, gender, and race.

Table 7-11. Summary of Recommended Values for Body Weight

Population	Mean	Upper Percentile	Multiple Percentiles
Adults	71.8 kg (See Table 7-2)	See Tables 7-4 and 7-5	See Tables 7-4 and 7-5
Children	See Table 7-3	See Tables 7-6 and 7-7	See Tables 7-6 and 7-7
Infants	Not Available	See Table 7-1	See Table 7-1

7.4. REFERENCES FOR CHAPTER 7

American Industrial Health Council (AIHC). (1994) Exposure factors sourcebook. AIHC, Washington, DC.

Brainard, J.; Burmaster, D. (1992) Bivariate distributions for height and weight of men and women in the United States. Risk Anal. 12(2):267-275.

Brorby, G.; Finley, G. (1993) Standard probability density functions for routine use in environmental health risk assessment. Presented at the Society of Risk Analysis Annual Meeting, December 1993, Savannah, GA.

Burmaster, D.E.; Lloyd, K.J.; Crouch, E.A.C. (1994) Lognormal distributions of body weight as a function of age for female and male children in the United States. Submitted 2/19/94 to Risk Analysis for publication.

Hamill, P.V.V.; Drizd, T.A.; Johnson, C.L.; Reed, R.B.; Roche, A.F.; Moore, W.M. (1979) Physical growth: National Center for Health Statistics Percentiles. American J. Clin. Nutr. 32:607-609.

National Center for Health Statistics (NCHS) (1987) Anthropometric reference data and prevalence of overweight, United States, 1976-80. Data from the National Health and Nutrition Examination Survey, Series 11, No. 238. Hyattsville, MD: U.S. Department of Health and Human Services, Public Health Service, National Center for Health Statistics. DHHS Publication No. (PHS) 87-1688.

Palisade. (1992) @Risk Users Guide. Palisade Corporation, Newfield, NY.

U.S. EPA (1989) Risk assessment guidance for Superfund, Volume I: Human health evaluation manual. Washington, DC: U.S. Environmental Protection Agency, Office of Emergency and Remedial Response. EPA/540/1-89/002.

Versar, Inc. (1991) Analysis of the impact of exposure assumptions on risk assessment of chemicals in the environment, phase II: uncertainty analyses of existing exposure assessment methods. Draft Report. Prepared for Exposure Assessment Task Group, Chemical Manufacturers Association, Washington, DC.

Table 7-9. Statistics for Probability Plot Regression Analyses
Male's Body Weights 6 Months to 20 Years of Age

Age	Lognormal Probability Plots Linear Curve	
	μ_3*	σ_3*
6 months to 1 year	2.23	0.132
1 to 2 years	2.46	0.119
2 to 3 years	2.60	0.120
3 to 4 years	2.75	0.114
4 to 5 years	2.87	0.133
5 to 6 years	2.99	0.138
6 to 7 years	3.13	0.145
7 to 8 years	3.21	0.151
8 to 9 years	3.33	0.181
9 to 10 years	3.43	0.165
10 to 11 years	3.59	0.195
11 to 12 years	3.69	0.252
12 to 13 years	3.78	0.224
13 to 14 years	3.88	0.215
14 to 15 years	4.02	0.181
15 to 16 years	4.09	0.159
16 to 17 years	4.20	0.168
17 to 18 years	4.19	0.167
18 to 19 years	4.25	0.159
19 to 20 years	4.26	0.154

* μ_3, σ_3 - correspond to the mean and standard deviation, respectively, of the lognormal distribution of body weight (kg).
Source: Burmaster et al., 1994

AIHC - Exposure Factors Sourcebook - The Exposure Factors Sourcebook (AIHC, 1994) provides similar body weight data as presented here. Consistent with this document, an average adult body weight of 72 kg is recommended on the basis of the NHANES II data (NCHS, 1987). These data are also used to derive probability distributions for adults and children. In addition, the Sourcebook presents probability distributions derived by Brainard and Burmaster (1992), Versar (1991) and Brorby and Finley (1993). For each distribution, the @Risk formula is provided for direct use in the @Risk simulation software (Palisade, 1992). The organization of this document, makes it very convenient to use in support of Monte Carlo analysis. The reviews of the supporting studies are very brief with little analysis of their strengths and weaknesses. The Sourcebook has been classified as a relevant rather than key study because it is not the primary source for the data used to make recommendations in this document. The Sourcebook is very similar to this document in the sense that it summarizes exposure factor data and recommends values. As such, it is clearly relevant as an alternative information source on body weights as well as other exposure factors.

7.3. RECOMMENDATIONS

The key studies described in this section was used in selecting recommended values for body weight. The general description of both the key and relevant studies are summarized in Table 7-10. The recommendations for body weight are summarized in Table 7-11. Table 7-12 presents the confidence ratings for body weight recommendations. The mean body weight for all adults (male and female, all age groups) combined is 71.8 kg as shown in Table 7-2. The mean values for each age group in Table 7-2 were derived by adding the body weights for men and women and dividing by 2. If age and sex distribution of the exposed population is known, the mean body weight values in Table 7-2 can be used. If percentile data are needed or if race is a factor, Tables 7-4 and 7-5 can be used to select the appropriate data for percentiles or mean values.

For infants (birth to 6 months), appropriate values for body weight may be selected from Table 7-1. These data (percentile only) are presented for male and female infants.

For children, appropriate mean values for weights may be selected from Table 7-3. If percentile values are needed, these data are presented in Table 7-6 for male children and in Table 7-7 for female children.

Body weight is a function of age, gender, and race and populations of many geographic regions may vary from the general population across geographic regions. Therefore, the user should make appropriate adjustments when applying the percentiles to other geographic regions.

The mean recommended value for adults (71.8 kg) is different than the 70 kg commonly assumed in EPA risk assessments. Assessors are encouraged to use values which most accurately reflect the exposed population. When using values other than 70 kg, however, the assessors should consider if the dose estimate will be used to estimate risk by combining with a dose-response relationship which was derived assuming a body weight of 70 kg. If such an inconsistency exists, the assessor should adjust the dose-response relationship as described in the appendix to Chapter 1. The Integrated Risk Information System (IRIS) does not use a 70 kg body weight assumption in the derivation of RfCs and RfDs, but does make this assumption in the derivation of cancer slope factors and unit risks.

Height and weight of 5,916 men and 6,588 women in the age range of 18 to 74 years were taken from the NHANES II study and statistically adjusted to represent the U.S. population aged 18 to 74 years with regard to age structure, sex, and race. Estimation techniques were used to fit normal distributions to the cumulative marginal data and goodness-of-fit tests were used to test the hypothesis that height and lognormal weight follow a normal distribution for each sex. It was found that the marginal distributions of height and lognormal weight for both men and women are Gaussian (normal) in form. This conclusion was reached by visual observation and the high R^2 values for best-fit lines obtained using linear regression. The R^2 values for men's height and lognormal weight are reported to be 0.999. The R^2 values for women's height and lognormal weight are 0.999 and 0.985, respectively.

Brainard and Burmaster (1992) fit bivariate distributions to estimated numbers of men and women aged 18 to 74 years in cells representing 1 inch height intervals and 10 pound weight intervals. Adjusted height and lognormal weight data for men were fit to a single bivariate normal distribution with an estimated mean height of 1.75 meters (69.2 inches) and an estimated mean weight of 78.6 kg (173.2 pounds). For women, height and lognormal weight data were fit to a pair of superimposed bivariate normal distributions (Brainard and Burmaster, 1992). The average height and weight for women were estimated from the combined bivariate analyses. Mean height for women was estimated to be 1.62 meters (63.8 inches) and mean weight was estimated to be 65.8 kg (145.0 pounds). For women, a calculation using a single bivarite normal distribution gave poor results (Brainard and Burmaster, 1992). According to Brainard and Burmaster, the distributions are suitable for use in Monte Carlo simulation.

Burmaster et al. (1994) (Submitted 2/19/94 to Risk Analysis for Publication) - Lognormal Distributions of Body Weight as a Function of Age for Female and Male Children in the United States - Burmaster et al. (1994), performed data analysis to fit normal and lognormal distributions to the body weights of female and male children at age 6 months to 20 years (Burmaster et al., 1994).

Data used in this analysis were from the second survey of the National Center for Health Statistics, NHANES II, which included responses from 4,079 females and 4,379 males 6 months to 20 years of age in the U.S. (Burmaster et al., 1994). The NHANES II data had been statistically adjusted for non-response and probability of selection, and stratified by age, sex, and race to reflect the entire U.S. population prior to reporting (Burmaster et al., 1994). Burmaster et al. (1994) conducted exploratory and quantitative data analyses, and fit normal and lognormal distributions to percentiles of body weight for children. Cumulative distribution functions (CDFs) were plotted for female and male body weights on both linear and logarithmic scales.

Two models were used to assess the probability density functions (PDFs) of children's body weight. Linear and quadratic regression lines were fitted to the data. A number of goodness-of-fit measures were conducted on data generated by the two models. Burmaster et al. (1994) found that lognormal distributions give strong fits to the body weights of children, ages 6 months to 20 years. Statistics for the lognormal probability plots are presented in Tables 7-8 and 7-9. These data can be used for further analyses of body weight distribution (i.e., application of Monte Carlo analysis).

Table 7-8. Statistics for Probability Plot Regression Analyses
Female's Body Weights 6 Months to 20 Years of Age

Age	Lognormal Probability Plots Linear Curve	
	μ_2*	σ_2*
6 months to 1 year	2.16	0.145
1 to 2 years	2.38	0.128
2 to 3 years	2.56	0.112
3 to 4 years	2.69	0.137
4 to 5 years	2.83	0.133
5 to 6 years	2.98	0.163
6 to 7 years	3.10	0.174
7 to 8 years	3.19	0.174
8 to 9 years	3.31	0.156
9 to 10 years	3.46	0.214
10 to 11 years	3.57	0.199
11 to 12 years	3.71	0.226
12 to 13 years	3.82	0.213
13 to 14 years	3.92	0.216
14 to 15 years	3.99	0.187
15 to 16 years	4.00	0.156
16 to 17 years	4.06	0.167
17 to 18 years	4.08	0.165
18 to 19 years	4.07	0.147
19 to 20 years	4.10	0.149

* μ_2, σ_2 - correspond to the mean and standard deviation, respectively, of the lognormal distribution of body weight (kg).

Source: Burmaster et al., 1994

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