U.S. ARMY CENTER FOR HEALTH PROMOTION AND PREVENTIVE MEDICINE

Technical Guide 312
Health Risk Assessment Methods and Screening Levels for Evaluating Office Worker Exposures to Contaminants on Indoor Surfaces Using Surface Wipe Data

June 2009

Approved for Public Release; Distribution Unlimited

USACHPPM
Readiness thru Health

ACKNOWLEDGEMENTS

This technical guide was prepared by the Environmental Health Risk Assessment Program, Directorate of Health Risk Management, U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM).

Subject matter experts from the following USACHPPM programs/directorates served as members of the USACHPPM TG 312 Work Group and contributed to this technical guide and provided peer review:

- Air Quality Surveillance Program (Directorate of Environmental Health Engineering)
- Environmental Health Consultant (Directorate of Laboratory Sciences)
- Environmental Health Risk Assessment Program (Directorate of Health Risk Management)
- Environmental Medicine Program (Directorate of Occupational and Environmental Medicine)
- Hazardous and Medical Waste Program (Directorate of Environmental Health Engineering)
- Health Effects Research Program (Directorate of Toxicology)
- Industrial Hygiene Field Services Program (Directorate of Occupational Health Sciences)

TECHNICAL ASSISTANCE

Questions, recommendations, and requests for technical assistance can be forwarded to USACHPPM—

U.S. Army Center for Health Promotion and Preventive Medicine
Directorate of Health Risk Management
Environmental Health Risk Assessment Program
ATTN: MCHB-TS-REH
5158 Blackhawk Road
Aberdeen Proving Ground, MD 21010-5403
DSN 584-2953 or Commercial 410-436-2953

TABLE OF CONTENTS

Chapter 1 INTRODUCTION 1
1.1 Purpose 1
1.2 References 1
1.3 Explanation of Acronyms and Abbreviations 1
1.4 Background and Scope 1
1.5 Application of Technical Guide 312 3
PART I BASIC APPROACH: FOR USE BY ALL ASSESSORS 5
Chapter 2 SUBSTANCE CHARACTERISTICS 5
2.1 Physical Characteristics 5
2.2 Substance Volatility 6
2.3 Substances for Which Surface Wipe Screening Levels Are Derived 6
Chapter 3 EXPOSURE ASSESSMENT AND SCREENING LEVEL DERIVATIONS 12
3.1 Exposure Assessment 12
3.2 Surface Wipe Screening Level Derivations 13
Chapter 4 TOXICOLOGY 16
4.1 Overview of Relevant Toxic Principles 16
4.2 Toxicity Values 17
4.3 Toxicity Assessment 19
4.4 Sources of Toxicity Data 19
Chapter 5 HEALTH RISK CHARACTERIZATION 21
5.1 Derivation 21
5.2 Utility 22
5.3 Limitations 23
5.4 Uncertainty Analysis 24
Chapter 6 SURFACE WIPE SCREENING LEVELS FOR NONPOROUS SURFACES 27
6.1 General Process 27
6.2 Target Levels 32
6.3 Substances with Existing Surface Wipe Standards and Recommended Levels 33
PART II SITE-SPECIFIC ASSESSMENT APPROACH: FOR USE BY EXPERIENCED RISK ASSESSORS 36
Chapter 7 CONTACT SURFACE CHARACTERISTICS 36
7.1 Surface Roughness 36
7.2 Porosity of Contact Material 37

TABLE OF CONTENTS (Continued)

	7.3 Surface Hardness	37
	7.4 Composition of Contact Material and Surface Treatment	37
	7.5 Surface Orientation	38
	7.6 Definition of Contact Surfaces for Technical Guide 312	38
Chapter 8	SURFACE SAMPLING METHOD CONSIDERATIONS	39
	8.1 Surface Sampling Methods	39
	8.2 Adjusting for Wipe Sampling Efficiency	44
Chapter 9	DETAILED OFFICE WORKER EXPOSURE ASSESSMENT	50
	9.1 Exposure Scenario Identification	50
	9.2 Estimating Exposure to Surface Contaminants	52
Chapter 10	QUANTIFYING INTAKE AND DOSE	120
	10.1 Intake Assumptions	120
	10.2 Dermal Absorbed Dose	120
	10.3 Intake form Incidental Ingestion	133
	10.4 Intake from Inhalation of Resuspended Particles	136

APPENDICES

Appendix A	References	139
Appendix B	Existing and Previously Documented Methods	159
Appendix C	Surface Wipe Screening Levels	171
Appendix D	Analytical Detection Limits Used to Develop Surface Wipe Screening Levels	176
Glossary		181

LIST OF TABLES

Table 2-1	Chemicals for Which Surface Wipe Screening Levels are Developed in TG 312	7
Table 5-1	Major Areas of Uncertainty	25
Table 6-1	Parameters and Values Used to Estimate Screening Levels in Equations 6-2 and 6-4	30
Table 8-1	Summary of Wipe Sampling Procedures and Guidelines	41
Table 8-2	Wipe Efficiency Data for Metals Sample from Smooth, Nonporous Surfaces	47

TABLE OF CONTENTS (Continued)

Table 9-1 Possible Routes of Exposure to Surface Contaminants on Nonporous Surfaces 52
Table 9-2 Recommended Surface Areas for Estimating Direct Dermal Contact (Office Workers) 56
Table 9-3 Summary of Experimental Data on Actual Hand Area Exposed—Contact with Smooth Surfaces Only 59
Table 9-4 Recommended Fd^1 Values for Office Workers 60
Table 9-5 Summary of Factors that Affect FT_{ss} Values 63
Table 9-6 Summary of Experimental Surface-to-Hand Transfer Efficiencies for Particles and Pesticide Residues (Smooth Surfaces Only) 66
Table 9-7 Summary of Hand-to-Mouth Transfer Data 77
Table 9-8 Estimated Mass of SERPACWA Transferred From Hand to Cigarette (USACHPPM 2003) 81
Table 9-9 Recommended FT_{hi} Values 81
Table 9-10 Recommended F_m Values 83
Table 9-11 Indoor Resuspension Rates Calculated and Compiled in Argonne National Laboratory 92
Table 9-12 Summary of Selected Resuspension Rates 97
Table 9-13 Particle Size Description Used by Various Agencies 99
Table 9-14 Indoor Surface Particle Size Distribution Data 102
Table 9-15 Particle Deposition Loss Rates 105
Table 9-16 Summary of Studies Used to Select a Deterministic Value for the Deposition Loss Rate 108
Table 9-17 Examples of Office Work Space Allocation 111
Table 9-18 Summary of Ventilation Rates for Commercial Buildings (Office Data Only) 116
Table 10-1 Dermal Absorption Fractions (ABS_d) 123
Table 10-2 Parameters and Values Used to Assess Mass Balance 126
Table 10-3 Remaining Surface Loads and Estimated Health Risks 128
Table 10-4 Recommended Event Frequencies for Different Workplace Activities/Behaviors 135
Table B-1 Summary of Past and Existing Methods for Evaluating Wipe Sample Data 170
Table C-1 Surface Wipe Screening Levels Based on Target Cancer Level of 1E-06 and Target Hazard Quotient of 1 171
Table D-1 Analytical Detection Limits 176

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

Figure 1-1 Schematic Diagram of the Applicability of TG 312 4
Figure 9-1 Darkened Image of Hand to Accentuate Areas in Actual Contact With Smooth Glass Surface 58
Figure 9-2 Dimensions of a Regular-Length Cigarette..... 83

CHAPTER 1
INTRODUCTION

Technical Guide 312 provides a method for evaluating potential health risks to office workers from exposure to chemical substances on indoor work surfaces. This technical guide is intended to provide users with the option of conducting a screening analysis or a site-specific characterization of potential health risks from exposure to contaminants.

1.1 Purpose

Technical Guide (TG) 312 provides a method for evaluating potential health risks to office workers from exposure to chemical substances on indoor work surfaces. The method may be used in two ways: (1) to establish health-based surface wipe screening levels (SWSLs) to be compared with environmental wipe sample results; or (2) to estimate cumulative health risks from exposure to chemical levels detected in wipe samples. Although this TG focuses on office worker exposures, the general method used to develop an exposure assessment may be adapted for other exposure scenarios by adjusting exposure factors.

1.2 References

Required and related publications are listed in appendix A.

1.3 Explanation of Acronyms and Abbreviations

Acronyms and abbreviations used in this TG are explained in the glossary.

1.4 Background and Scope

Surface sampling of indoor surfaces may be performed to determine whether a building is safe for reentry following an event (for example, fire, pesticide application) or use for a different purpose (for example, industrial to office). Surface wipe sampling results may be used to assess either the degree of contamination before cleanup or to determine whether post-abatement (also post-remediation, post-clearance) actions were effective. Thus, there is a need to develop an approach to characterize potential health risk to exposed populations using surface wipe sampling results and to provide SWSLs to facilitate initial assessments. When submitting samples to the laboratory supporting any surface wipe sampling project, users need to make sure laboratory personnel understand that the detection levels for the analytical results must be below the calculated screening levels for the final results to support health-based risk assessments.

Technical Guide 312 provides a method that can be used to characterize potential health risks from exposure to indoor contaminants. One of the first steps in developing this method was to evaluate existing and previously documented methods to avoid duplicating efforts. Appendix B presents some methods identified during this review process. Many of these methods were developed for a specific purpose and cannot be easily adapted for general use. For example, methods used to assess industrial worker exposures via dermal contact are generally not applicable for nonindustrial exposures because required input parameters are developed for tasks not typically encountered outside an industrial setting. Therefore, these methods were not adopted outright for TG 312. Instead, TG 312 builds on the approach previously used by the U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM) (USACHPPM, 1999a; May et al. 2002).

The key to the assessment approach was to develop a method for completing a generic exposure assessment based on a specific exposure scenario. The method assumes that people may be exposed to chemicals on room surfaces by three potential exposure routes: absorption of chemical through skin contact with contaminated surfaces, incidental ingestion by hand-to-mouth behaviors, and inhalation through breathing resuspended particles. The method development was hampered by both the lack of validated exposure models and the lack of data needed to characterize exposure to indoor surface contamination. Despite these limitations, TG 312 used results of literature searches and professional judgments to make assumptions, select exposure factors, and adapt U.S. Environmental Protection Agency (USEPA) exposure and risk equations. Technical Guide 312 documents these areas of uncertainty and highlights critical data gaps in order to foster research in those areas. Only by doing this can researchers understand what kind of data is needed and how to adopt consistent experimental designs to reduce uncertainty. Therefore, the methods and input parameters presented in TG 312 can always be improved as new data become available.

The scope of TG 312 is limited to the office work scenario. This limited focus permits the development of a defensible method that can be modified for other exposure scenarios. This scenario represents a common environment understood by most people and includes only adults, thereby simplifying assumptions.

In addition to the lack of exposure data and limited scope, evaluating potential health risks from acute exposures (for example, a one-time exposure or a 1-hour (hr) exposure) is not recommended at this time because of the lack of dermal toxicity data to characterize health effects from short-term exposures. When more acute toxicity data become available, the methods presented in TG 312 can still be applied by modifying assumptions and input values so they reflect those of short-term exposures.

1.5 Application of Technical Guide 312

Technical Guide 312 is divided into two parts. Part I (chapters 2 through 6) is written for all users of the guide and provides the health professional using the guide with the technical details to apply the recommended SWSLs to initial risk assessments. Part II (chapters 7 through 10) contains details on the literature search results and judgments used to develop exposure factors, assumptions, and associated risk calculations. These technical discussions are deliberate and are intended to document the rationale for the method and to give experienced risk assessors an understanding of the factors that could affect final health risk estimates. Experienced risk assessors may then apply the basic approach and equations to other exposure scenarios by tailoring exposure factors and assumptions to complete site-specific risk assessments.

Figure 1-1 provides a step-wise check for users to determine whether the assumptions used to develop recommended exposure models and associated input parameters in TG 312 apply to their scenario. This is not to suggest that the exposure models in this guide cannot be used for those other scenarios. As stated above, experienced risk assessors may evaluate those assumptions and input parameters to determine whether they could be applied. For example, adjustments for wipe efficiencies are based on information for wetted surface wipes. If the user wants to characterize health risks or develop SWSLs for other surface sampling methods (for example, vacuum sampling methods), the user should assess whether the adjustment factors are appropriate for those methods. If not, the user needs to document uncertainties or invest time researching appropriate values.

As shown in figure 1-1, TG 312 was developed to give users the option of conducting a screening analysis or a site-specific characterization of potential health risks from exposure to contaminants on indoor surfaces. Alternately, if surface wipe levels exceed their SWSLs at the screening phase, users have the option to proceed to a detailed, site-specific analysis.

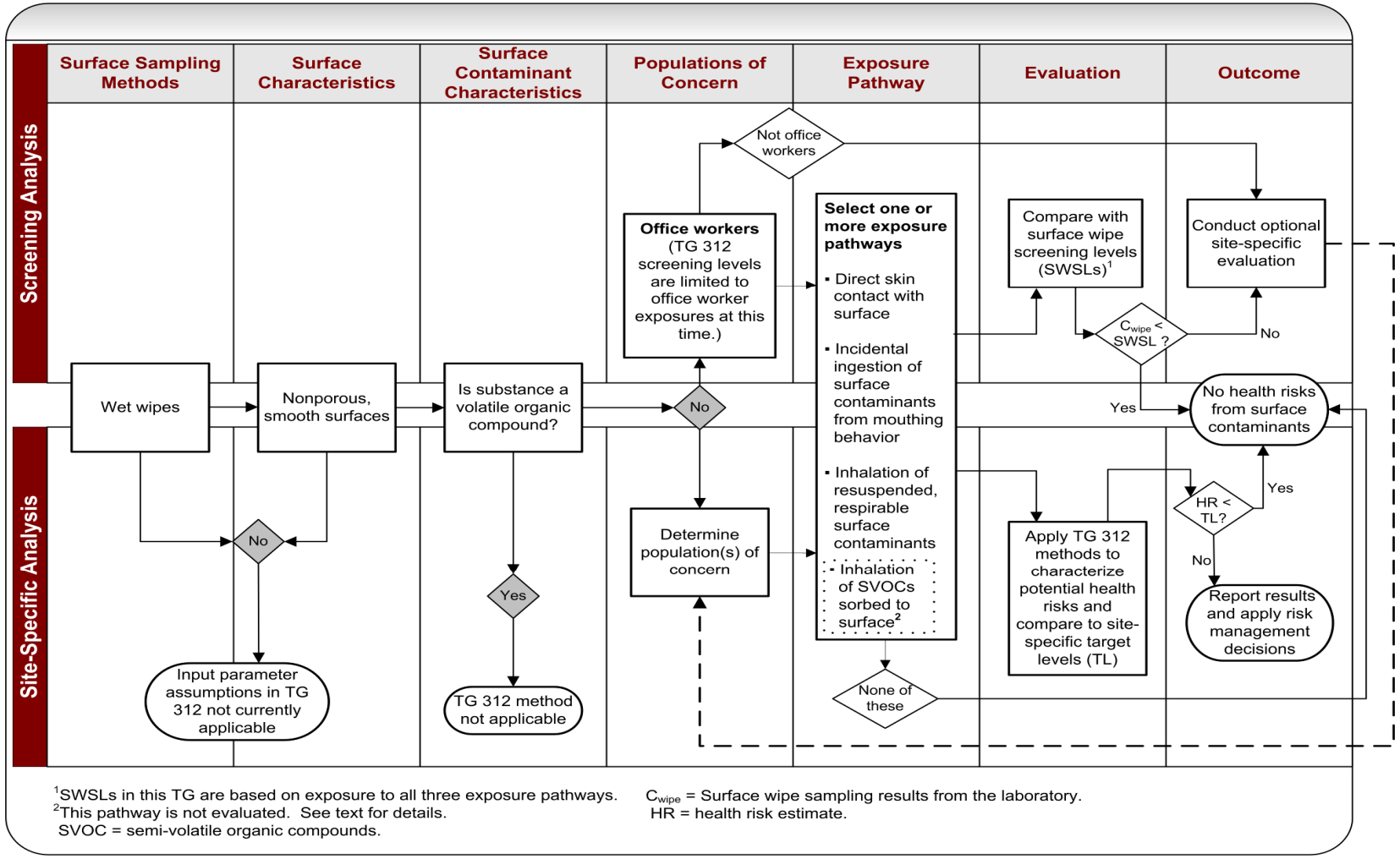

Figure 1-1. Schematic Diagram of the Applicability of TG 312

PART I
BASIC APPROACH: FOR USE BY ALL ASSESSORS

CHAPTER 2
SUBSTANCE CHARACTERISTICS

How a chemical substance behaves in the environment, is absorbed into the body, or metabolized once absorbed, are all largely influenced by the substance's physicochemical properties. Therefore, it is necessary to consider these properties when selecting the appropriate models and input values to estimate exposure. This chapter discusses those physicochemical properties most relevant to the purposes of this technical guide.

2.1 Physical Characteristics

One physical characteristic little discussed in the literature, but which may impact the amount of substance transferred from one medium to another (for example, surface to skin), is the substance's "physical form" as it exists on the surface. Since this TG does not address liquid spills, the two physical forms of relevance here are—

- Particulate (free or bound to other particles such as dust).
- Film layer such as that left behind after application of oil-based pesticides.

Currently, experimental studies aimed at measuring substance transfer from the surface to the skin do not identify whether the test substance is a particle or film. While not an issue for studies that use particles (for example, powder) as the test substance, the problem is more evident in studies involving oil-based pesticide "residue" on the surface. When applied in a natural indoor environment, this residue most likely consists of both physical forms, the combination of which depends on the dustiness of the surface. Controlled experimental studies, however, often use pre-cleaned or new test surfaces (see Clothier 2000). Although this makes sense from an experimental viewpoint because it permits researchers to control variable factors, measurements from controlled studies may not reflect those of natural environments. However, measurements from these studies could be more applicable for assessing wipe samples taken after surfaces have been remediated. More data is needed to determine the impact, if any, and significance of a substance's physical state on substance transfer from one medium to another.

2.2 Substance Volatility

This TG does not recommend that wipe samples be used to evaluate potential health risks from exposure to volatile organic compounds (VOCs) because the primary exposure pathway for VOCs is from inhalation of these substances in the vapor form rather than the particulate form. Therefore, if VOC contamination is suspected, ambient air samples should be taken in lieu of surface wipe samples.

Generally defined, a VOC is an organic compound with a high rate of vaporization at room temperature. However, when using the physicochemical properties of a compound to characterize the volatility of a substance, different classification methods are available (USACHPPM 2008). Therefore, this TG has adopted the VOC classification scheme used by the USACHPPM Environmental Health Risk Assessment Program (EHRAP) (USACHPPM 2008). The default approach is based on the boiling point of a substance, with volatiles defined as those with a boiling point less than 100 degrees Celsius (<100 °C). When boiling point information is not available, volatility is determined from the Henry's Law constant and molecular weight of the substance (as in section 5 of USACHPPM EHRAP Standard Operating Procedure (SOP) No. 39-06-03 (USACHPPM 2008)).

2.3 Substances for Which Surface Wipe Screening Levels Are Derived

For this TG, SWSLs were developed for a list of substances most commonly sampled by the USACHPPM Hazardous and Medical Waste Program. This list includes metals, chemical warfare agents (CWAs), dioxins/furans, explosives, herbicides, pesticides, and other semi-volatile organic compounds (SVOCs). Table 2-1 lists these substances; appendix C lists the SWSLs.

Table 2-1. Chemicals for Which Surface Wipe Screening Levels are Developed in TG 312

Substance Classification	Chemical Name
Metals	Aluminum Arsenic Barium Beryllium Boron Cadmium Chromium (III) Chromium (VI) Cobalt Copper Iron Manganese Mercury Molybdenum Nickel Selenium Silver Strontium Tin Titanium Vanadium Zinc
Explosives	1,3-Dinitrobenzene 2,4-Dinitrotoluene 2,6-Dinitrotoluene HMX (Cyclotetramethylenetetranitramine) Nitrobenzene Nitroglycerin 2-Nitrotoluene 3-Nitrotoluene 4-Nitrotoluene RDX (Cyclotrimethylenetrinitramine) Tetryl (Trinitrophenylmethylnitramine) 1,3,5-Trinitrobenzene 2,4,6-Trinitrotoluene

Table 2-1. Chemicals for Which Surface Wipe Screening Levels are Developed in TG 312 (continued)

Substance Classification	Chemical Name
Neutral Herbicides	Bentazon Dicamba (2,4-Dichlorophenoxy)acetic acid (2,4-D) 4-(2,4-Dichlorophenoxy)butyric acid(2,4-DB) Mecoprop (Methylchlorophenoxypropionic (MCPP)) 2-Methyl-4-chlorophenoxyacetic acid (MCPA) Pentachlorophenol Picloram Silvex (2,4,5-TP) Trichlorophenoxyacetic acid
Pesticides (Organophosphorus, Organochlorine Organonitrogen, Polychlorinated Biphenyls (PCBs))	Alachlor Aldrin Aroclor 1016 Aroclor 1254 Atrazine Benefin Chlordane (technical) Chlorfenvinphos Chlorothalonil Chlorpyrifos Chlorpyrifos methyl Dacthal®[1] (Dimethyl tetrachloroterephthalate (DCPA)) p,p'-DDD (dichlorodiphenyldichloroethane) p,p'-DDE (dichlorodiphenyldichloroethylene) p,p'-DDT (dichlorodiphenyltrichloroethane)Diazinon Dichlorvos Dieldrin Dimethoate Disulfoton Endosulfan Endrin Ethion Fonofos Heptachlor Heptachlor epoxide Hexachlorobenzene beta-Hexachlorocyclohexane (beta-BHC)

Table 2-1. Chemicals for Which Surface Wipe Screening Levels are Developed in TG 312 (continued)

Substance Classification	Chemical Name
Pesticides (Organophosphorus, Organochlorine Organonitrogen, Polychlorinated Biphenyls (PCBs)) (continued)	Lindane Malathion Methoxychlor Methyl parathion Mirex Oxadiazon Parathion (Parathion-ethyl) Pentachloronitrobenzene Permethrin Phorate Phosmet Pronamide Propazine Ronnel Simazine Terbufos Tetrachlorvinphos Toxaphene Trifluralin Vinclozolin
Dioxins/Furans and Dioxin-like PCBs Congeners	2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) (Designed to compare to 2,3,7,8-TCDD toxicity equivalent exposure point concentration) (See paragraph 4.4 for further details.)
Chemical Warfare Agents and Degradation By-products	S-[2-Diisopropylamino)ethyl]methyl-phosphonothioic acid (EA 2192) Diisopropyl methylphosphonate 1,4-Dithiane Ethyl methylphosphonic acid (EMPA) Sarin (GB) Isopropyl methyl phosphonic acid Lewisite oxide Methylphosphonic acid Sulfur mustard (or H/HD) Thiodiglycol VX

Table 2-1. Chemicals for Which Surface Wipe Screening Levels are Developed in TG 312 (continued)

Substance Classification	Chemical Name
Semi-volatile Organic Compounds	Acenaphthene Anthracene Benz[a]anthracene Benzo(b)fluoranthene Benzo(k)fluoranthene Benzo[a]pyrene Benzyl alcohol Bis(2-chloroethyl) ether Bis(2-chloro-1-methylethyl) ether Bis(2-ethylhexyl) phthalate Butyl benzyl phthalate 4-Chloroaniline 2-Chloronaphthalene 2-Chlorophenol Chrysene o-Cresol p-Cresol Dibenz(a,h)anthracene Dibenzofuran Dibutyl phthalate 1,2-Dichlorobenzene 1,3-Dichlorobenzene 1,4-Dichlorobenzene 2,4-Dichlorophenol Diethyl phthalate 2,4-Dimethylphenol 4,6-Dinitro-o-cresol 2,4-Dinitrophenol Di-n-octyl phthalate Fluoranthene Hexachlorobutadiene Hexachlorocyclopentadiene Hexachloroethane Indeno(1,2,3-cd)pyrene Isophorone 3-Methyl-4-chlorophenol 2-Methylnapthalene Naphthalene

Table 2-1. Chemicals for Which Surface Wipe Screening Levels are Developed in TG 312 (continued)

Substance Classification	Chemical Name
Semi-volatile Organic Compounds (continued)	2-Nitroaniline 3-Nitroaniline 4-Nitroaniline N-Nitrosodimethylamine N-Nitrosodiphenylamine N-Nitrosodipropylamine Phenol Pyrene 1,2,4-Trichlorobenzene 2,4,5-Trichlorophenol 2,4,6-Trichlorophenol
Note: [1]Dacthal® is a registered trademark of Diamond Alkali Company, Cleveland, Ohio.	

CHAPTER 3
EXPOSURE ASSESSMENT AND SCREENING LEVEL DERIVATIONS

The exposure assessment seeks to quantify the amount of a chemical contacting the outer boundary of a human and can provide an estimate of internal dose. The exposure assessment process is a critical element in the health risk assessment because the output provides an estimate of chemical intake. Chemical intake is the amount of the chemical ingested, inhaled, or absorbed through the skin and is used to estimate health risk. The challenge and major work effort in this TG is developing the methodology to conduct a generic exposure assessment for typical office workers potentially exposed to chemicals deposited on nonporous work surfaces.

3.1 Exposure Assessment

Exposure assessments can be completed with a variety of approaches (USEPA 1992a). For this application, the exposure assessment is based on an evaluation of a specific scenario (typical office work). A health risk assessor uses an evaluation of an exposure scenario to determine the concentrations of chemicals in a medium or location and link this information with the time and way that individuals or populations are in contact with the chemical. The exposure scenario serves as a calculation tool to help the assessor develop estimates of exposure, dose (intake), and risk. The scenario provides the assessor a picture of how the exposure is taking place and will help organize the data and calculations. The set of assumptions about how this contact takes place is based on the specific exposure scenario. The details on selection of assumptions, equation parameters, default values, and associated uncertainty used to characterize exposure for this TG are contained in Part II, chapters 9 and 10. Health professionals wishing to apply this approach to other potential scenarios need to review chapters 9 and 10 and compare the soundness, validity, and uncertainty of the underlying assumptions to the new scenario.

In this TG, exposure assumptions are provided only for an adult office worker population whose job functions involve the performance of typical office work tasks while the worker is seated at a desk. Literature searches and professional judgment were used to estimate behavioral and physical factors that impact worker exposure from surface contamination. When a worker performs an activity on a contaminated surface, some of the surface contaminants may be transferred to the skin. This transfer to skin can lead to both a dermal-absorbed dose and ingestion intake related to hand-to-mouth transfer. The inhalation exposure used for this scenario is intake as a result of activity that causes settled material to become resuspended in the air. Typical USEPA risk assessments are based on the USEPA generic equation for calculating chemical intakes (USEPA 1989b). (See equation 3-1.) The generic equation is then adapted for

the three routes of exposure designed to estimate potential intake from dermal, ingestion (associated with hand-to-mouth transmission), and inhalation (resuspended particles) routes of exposure.

Equation 3-1

$$I = C \times \frac{CR \times EFD}{BW} \times \frac{1}{AT}$$

Where:

I = intake (milligram/kilogram (mg/kg) body weight-day)
C = chemical concentration
CR = contact rate (inhalation rate, ingestion rate, absorption rate)
EFD = exposure frequency and duration
BW = body weight
AT = averaging time

This TG modifies this generic intake equation by applying exposure factors specifically developed for the office worker scenario. The details on the selection and applications of these exposure factors are provided in Part II, chapters 9 and 10.

3.2 Surface Wipe Screening Level Derivations

In USEPA risk assessments, carcinogenic risks and noncarcinogenic hazards are typically calculated based on the route-specific intake and the route-specific toxicity values. The total risk for a chemical or multiple chemicals on a site is the sum of the risk associated with dermal, inhalation (resuspended particles), and ingestion exposure. Often, the intake calculations are based on default USEPA exposure parameters (EPs) for typical scenarios, such as "residential" or "industrial," and a calculated exposure point concentration for each chemical meant to be representative of all samples taken in that media. When risks or hazards are summed, they are usually compared to an "acceptable" risk such as 1×10^{-6} or a hazard ratio (HR) such as 1. The simple equations for carcinogenic risk and noncancer effects are as follows:

Equation 3-2

Cancer Risk = Lifetime Average Daily Dose x Cancer Slope Factor (for each exposure route)

Total Cancer Risk = Dermal Risk + Inhalation Risk + Ingestion Risk

$$\text{Noncaner Hazard Ratio (HR)} = \frac{\text{Average Daily Dose (ADD)}}{\text{Reference Dose (RfD)}}$$

$$\text{Total Noncancer HR} = \text{Dermal HR} + \text{Inhalation HR} + \text{Ingestion HR}$$

For estimating acceptable SWSLs for chemicals of concern, the calculation sequence is reversed. The basic intake and risk equations are combined, and an acceptable surface contamination load per unit area is calculated for each chemical of concern by determining that amount of chemical load that equates to the target "acceptable" risk level. Acceptable risks for the recommended SWSLs listed in the table in chapter 6 are set at $1x10^{-6}$ for carcinogenic risk and an HR of 1 for noncarcinogenic hazard. Chapter 6 contains details on the specific equations used to generate the SWSL. The following is a simplified example to illustrate the calculation:

Equation 3-3

$$THR = \left[\frac{C \times EP\ (derm)}{RfD\ (derm)}\right] + \left[\frac{C \times EP\ (ing)}{RfD\ (ing)}\right] + \left[\frac{C \times EP\ (inh)}{RfD\ (inh)}\right]$$

Where:

THR	=	target hazard ratio
C	=	the chemical loading on surface
EP	=	the combined exposure parameters for the specific exposure route
derm	=	dermal
RfD	=	reference dose
ing	=	ingestion
inh	=	inhalation

Rearranging and solving for C yields the chemical loading that represents the selected risk level (THR = 1 for this example):

Equation 3-4

$$C = \frac{THR}{\left[\frac{EP\ (derm)}{RfD\ (derm)}\right] + \left[\frac{EP\ (ing)}{RfD\ (ing)}\right] + \left[\frac{EP\ (inh)}{RfD\ (inh)}\right]}$$

When a chemical has both cancer and noncancer toxicity values, the final SWSL for that chemical is based on the lower of the two calculated values. This screening level value is then compared to the level of detection for the chemical of concern. If the calculated risk-based screening level is below the level of detection, then the level of detection becomes the recommended analytically based SWSL. This detection level logic is vitally important for users to understand. If the laboratory reports a detection level above the calculated health-based SWSL, then the usefulness of the sampling results for protecting health needs to be evaluated based on the magnitude of the delta between the health-based screening level and the reported level of detection. Therefore, health professionals need to ensure that they specify the required detection limits (DLs) when requesting sampling analysis.

CHAPTER 4
TOXICOLOGY

In the context of this TG, toxicology is used to assess the degree to which exposures to chemicals located on surfaces in an office environment may cause an adverse health effect to adult office workers. An essential tenet of toxicology and health risk assessment is that a toxic effect is dependent on the intake of the chemical at a target site. The previous chapter described the methodology to estimate a dose based on an exposure assessment. This chapter describes some of the key toxicology concepts used to develop the toxicity assessment.

4.1 Overview of Relevant Toxic Principles

The potential for a chemical to cause an adverse toxic response depends on many different factors, some of which include—

- Physical properties (physical state, solubility).
- Chemical properties (pH, reactivity).
- Inherent toxicity (dose response, toxic effect).
- Exposure scenario (route of exposure, duration of exposure, frequency of exposure).
- Target susceptibility (age, size, general health).

Toxic effects are grouped into two broad categories: local (portal-of-entry) effects and systemic effects. Local or portal-of-entry effects refer to effects at the site of initial chemical contact. These can be direct cellular damage to the skin, lungs or gastrointestinal tract. Systemic effects refer to impacts to one or more specific body systems or tissues (kidney, central nervous system, liver, etc.) caused by the chemical entering the body's circulatory system and being distributed throughout the body.

The response to a chemical exposure may vary by the route of exposure. The severity of a toxic effect is a function of the concentration of the toxic chemical which actually reaches a site of action. As a result of a dermal exposure, chemicals may react with the skin surface and cause local (portal-of-entry) irritation and cell destruction. Strong acids and bases are examples of chemicals that can damage or destroy cells and/or cause skin irritation. With repeated exposures to some chemicals, a person's skin can become sensitized, and the person can experience a range

of allergic-type reactions. A common example of this skin reaction is a rash caused by repeated exposures to nickel. Other examples of direct skin effects include contact dermatitis, photosensitivity, ulcers, pigment changes, infection, or skin cancer. A third possible outcome from dermal exposure is the chemical passing through the skin layers to the blood vessels beneath the skin and entering the bloodstream. When the chemical enters the bloodstream, a systemic effect is possible, and the final toxic effect will depend on the target organ.

4.2 Toxicity Values

The term "toxicity values" refers to human health effect (dose-response) criteria values derived from toxicology or epidemiology studies and assessments. The USACHPPM EHRAP has developed an SOP which describes the algorithm used by USCHPPM health risk assessors to select appropriate chronic toxicity criteria (USACHPPM 2006b). The USEPA Integrated Risk Information System (IRIS) electronic database is the first choice for selection of toxicity values (USEPA 2008). The IRIS is a collection of peer-reviewed documents and health criteria values that may be used to assess health risk from exposure to various substances in the environment.

Toxicity values can differ by exposure pathway partly because the exposure route can alter the chemical and the doses required to elicit a toxicological response. For example, substances inhaled may be readily absorbed by the lung, ingested substances are absorbed and perhaps altered via the gastrointestinal tract, and skin can serve as a barrier to penetration for some chemicals. Currently, most health-based toxicity values are developed for exposures via ingestion and inhalation, because data for dermal exposures are limited. For dermal exposures, the USEPA (2004b) does provide guidance for extrapolating from toxicity data developed for ingestion exposures. The method presented, as well as experimental protocols used to estimate the fraction of chemicals absorbed through the skin (or dermal absorption fraction (ABS_d)) values, assumes the skin acts as a partial barrier and that substances absorbed contribute to systemic (for example, kidney, liver) toxicity. Although the USEPA (2004b) recognizes the potential for direct portal-of-entry effects in the skin, the agency does not address local dermal toxicity at this time because of limited information on portal-of-entry effects. This is a limiting factor and adds to the uncertainty for any risk assessment including the SWSLs.

Noncancer effects are assessed with oral reference doses (RfDs) and inhalation reference concentrations (RfCs) for effects known or assumed to be produced through a nonlinear (possibly threshold) mode of action. The RfD is defined as an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of adverse effects during a lifetime.

The inhalation RfC is the concentration of a chemical in air that is unlikely to have an adverse health effect if inhaled continuously over a lifetime but that provides a continuous inhalation exposure estimate.

Cancer effects are currently assessed as linear (non-threshold) effects with oral slope factors and oral and inhalation unit risks (URs) for carcinogenic effects. Cancer slope factors (CSFs) and URs are used to estimate the risk of cancer associated with exposure to a carcinogenic or potentially carcinogenic substance. Non-threshold cancer models assume that each molecule of a carcinogen has a risk, although that risk is infinitesimally small. Risk increases with increased exposure dose. Therefore, the USEPA developed an "acceptable" level of risk, rather than a threshold. The slope factor is risk per unit dose, which allows for the calculation of a lifetime incremental risk for the dose the population faces. The USEPA has chosen 10^{-4} to 10^{-6} (one in 10,000 to one in a million) incremental risk—that is how much more of a risk we face from exposure to this chemical compared to the everyday risk of cancer we all face in a lifetime.

The IRIS database contains chronic ingestion dose-response data and lacks direct or systemic dermal dose response. Therefore, systemic dermal toxicity values need to be derived from ingestion toxicity data. The USEPA endorses oral-to-dermal extrapolations to develop dermal toxicity values for risk assessments of systemic health effects. In addition to guidance on sources of toxicity data, USACHPPM EHRAP SOP No. 39-01-03 also discusses how dermal toxicity data can be extrapolated from a substance's oral toxicity data according to USEPA guidance. Since the oral dose is calculated as an administered dose but the dermal dose is calculated as an absorbed dose (that is, how much actually reaches the systemic circulation), the approach recommends application of a gastrointestinal (GI) absorption factor to the oral toxicity data (USEPA 2004b). This adjusts the oral toxicity value for differences in the meaning of "dose." Since limited GI absorption factors are available, a default GI absorption of 100 percent is often applied, resulting in identical toxicity values being used to assess oral and dermal toxicity. However, for substances where the GI absorption efficiency is less than 50 percent (the case for many metals), actual GI absorption factors are applied to the oral toxicity values. This can have the effect of making the dermal "dose-response," and therefore the toxicity value, appear more than twice as toxic.

Users of this TG need to understand the key concept that there are significant uncertainties associated with the estimation of dermal toxicity criteria using this method, notwithstanding the endorsement of the USEPA. The differences in route of entry between dermal and oral go beyond the "portal-of-entry" effects. Circulation and metabolism can differ greatly during and after systemic absorption. Accurate estimation of administered dose to the skin is problematic, and then accurately estimating the absorbed dose from that administered dose compounds the

uncertainty. In addition, as stated above, any time an adjustment is made from the 100-percent-absorption assumption of the oral toxicity value, the dermal value tends to be "more toxic" per unit dose.

4.3 Toxicity Assessment

USACHPPM EHRAP SOP No. 39-01-03 describes the purpose of a toxicity assessment in a health risk assessment as the methodology used to select appropriate chronic toxicity criteria (USACHPPM 2006b). Environmental surface wipe sampling data coupled with exposure assessment equations provide the information to calculate estimated doses which are combined with the toxicity values of each chemical to estimate potential cancer and noncancer risks. Appropriate RfDs and RfCs are used to estimate noncancer health hazards while the CSF is used to estimate carcinogenic risks.

As previously discussed, toxicity values are grouped by route of exposure, which can be of different toxicity depending on the route. Therefore, a chemical may have an oral RfD, a dermal RfD, and an inhalation RfC which are applied to the estimated intake for each exposure route. Most often, only oral and/or inhalation toxicity values are available for a particular chemical. Dermal toxicity values are rare or nonexistent and require extrapolation usually from the oral.

4.4 Sources of Toxicity Data

The USACHPPM EHRAP SOP No. 39-01-03 provides a tiered approach for selecting toxicity values for assessing chronic (>7 years) exposures (USACHPPM 2006b). The selection process follows general USEPA guidance which recommends the following toxicity value hierarchy (USEPA 2003b):

- Tier 1: USEPA IRIS.

- Tier 2: USEPA Provisional Peer-Reviewed Toxicity Values (PPRTV).

- Tier 3: Other sources, with priority given to sources that are the most current, transparent and publicly available, and peer-reviewed.

The USACHPPM EHRAP SOP No. 39-01-03 defaults to a specific hierarchy within Tier III by providing additional sources from which toxicity data may be gathered. The SOP also presents recommendations for selecting toxicity values when toxicity data/values are not available from the preferred sources, as well as discussions on special considerations for some substances. For example, most polychlorinated dioxins, polychlorinated furans, and dioxin-like (coplanar)

polychlorinated biphenyls (PCBs) do not have their own toxicity values even though they share the same mechanism of toxicity. The assessment of these compounds requires that the wipe sample mass (micrograms per 100 square centimeters (µg/100 cm^2)) for each compound be multiplied by its toxicity equivalency factor (TEF), and a sum total of the TEF-adjusted mass of all dioxin-like compounds (referred to as the toxicity equivalent mass) is then compared to the SWSL for 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD). Additional details can be found in USACHPPM EHRAP SOP No. 39-01-03.

CHAPTER 5
HEALTH RISK CHARACTERIZATION

Risk characterization is the final step in the health risk assessment process. The results of hazard identification, exposure assessment, and toxicity assessment are integrated to express any health risk to the population of concern in quantitative and qualitative terms. A risk characterization includes numerical expressions of risk that are accompanied by text interpreting, qualifying, and placing the results into context. Characterization of human exposure to chemicals based on wipe sampling data is a difficult task due to lack of data and validated exposure models. In the context of TG 312, this chapter will discuss the derivation, utility, limitations and uncertainty of the calculated SWSLs.

5.1 Derivation

As discussed in chapter 3, TG 312 uses USEPA methodology to derive acceptable SWSLs. The approach includes developing exposure factors specific to the office worker scenario and applying these factors to the generic USEPA equation for estimating chemical intakes from dermal, ingestion and inhalation routes of exposure. Next, acceptable target risk (TR) levels of 10^{-6} for cancer risk and a HR of 1 for noncancer risk were selected, and appropriate toxicity values chosen. Then, the three USEPA risk calculation equations for each exposure route can be "reversed" and combined to calculate an "acceptable" surface load for each chemical of concern.

Chapters 9 and 10 of this TG provide details on how intake is modeled for each route of exposure from surface contamination exposure. For the dermal and ingestion exposure assessments, intake calculations were based on selecting parameters for exposure factors on a per event basis. This approach allows risk assessors to compare the default values recommended in this TG to their own site-specific values. The risk assessor can modify default parameters to better characterize a specific exposure scenario.

For typical health risk assessments, the environmental sampling results are used to calculate the exposure point concentrations; these calculated concentrations are used to estimate intake and serve as the source of "C" in the risk assessment equations. For the screening values, the calculated "acceptable" level for that chemical as surface contamination is compared to each wipe sample taken. When the wipe samples are above the screening values for a chemical, or multiple chemicals are approaching the screening values, the risk assessor may determine that a "typical" health risk assessment is indicated for the site, with more site-specific EPs. Health professionals using these screening values may need to discuss these acceptable risk levels with the specific risk manager to ensure the risk levels are applicable to the situation. The details on the specific equations and calculations are contained in chapters 9 and 10 of this TG.

5.2 Utility

These screening levels can be used to determine if chemical surface loadings are acceptable under general conditions that are typical of an office environment. The screening levels should not be used when—

- A renewable source of contamination exists.
- Frequent surface contact will result in significantly greater exposure/surface area (SA) assumptions.
- Sampling of porous surfaces takes place.
- Workday hours vary significantly from an 8-hour day.
- Potentially exposed populations are not healthy adults.
- The exposure scenario includes acute exposures.
- Potential exposure to volatile organics exists.
- Sampling protocol is different from that described in the SOP developed by the USACHPPM Directorate of Environmental Health Engineering (DEHE) (USACHPPM 2006a).

Health professionals applying the surface levels developed by this methodology need to be aware that these values provide a screening tool and are not absolute predictors of adverse health effects. Environmental surface wipe results below these screening levels indicate areas where the surface contamination for the chemical of concern is below the TR level. Environmental surface wipe results above the screening levels indicate a potential for health risk above the TR level and further site/chemical-specific risk assessment activity. The screening levels in this guide are not meant to be used to draw definitive lines between safe and unsafe environmental conditions. Specifically, a site-specific assessment may determine that the conditions assumed in the screening level development are in fact over-conservative and that there are no unacceptable risks. On the other hand, the site-specific assessment may provide further evidence of a specific health risk that requires remedial action.

Two previous USACHPPM studies using wipe samples to characterize health risk concluded that the dermal and ingestion exposure routes were the major contributors to the health risk. These conclusions are also reflected in the exposure assessment chapters (by route of exposure) in this TG. In one study, the highest contributor to the carcinogenic risk was the dermal pathway which included cadmium exposure. The noncarcinogenic risk was also primarily a result of the dermal exposure pathway, although about a third of the risk was due to incidental ingestion of dust. The inhalation pathway did not contribute significantly to either the carcinogenic or noncarcinogenic risk (USACHPPM 1998). Another USACHPPM study conducted a sensitivity analysis on wipe sampling results in an industrial setting and found four model variables highly correlated to calculated screening values. These variables included hand-to-mouth events, contact frequency with a surface, a fraction of chemical transferred from skin to mouth, and dermal surface available for ingestion (May et al. 2002).

5.3 Limitations

Potential sources of uncertainty can be associated with the parameters selected for the risk assessment model and the inherent uncertainty with the model itself. Some sources of uncertainty may be reduced by further data collection or refinement of model parameters. Collecting more environmental samples can better characterize the environmental conditions, and further literature searches may provide better estimates for model parameters.

Calculated SWSLs are sensitive to assumptions and default input variables. Assumptions, uncertainty, and limitations are unavoidable because of gaps in our knowledge concerning exposure conditions and toxic responses. The screening level values in this TG have the inherent scientific uncertainty associated with the health-based reference dose and the UR values used in the calculations and as described in the USEPA IRIS. The exposure assessment used in this TG to develop the screening values also has uncertainties related to characterizing the three routes of exposures used to develop the exposure assessment.

Health professionals applying this screening level methodology need to consider the potential for multiple chemicals within acceptable risk ranges having an additive impact on total risk. Screening level values are developed for single chemicals and are evaluated against their chemical-specific screening level value. It is possible that all individual chemicals present may be below their specific screening level values, yet the sum of the risk may exceed an acceptable value. Multiple chemical exposure scenarios may warrant more detailed risk assessments if there is a question.

Users of TG 312 need to understand that the screening level values calculated by this methodology are health-based values. Therefore, if the substance of concern is relatively nontoxic, then the calculated screening values may be higher than would be acceptable by good work practices, or standards of "clean" based on practice in other fields of expertise, or good housekeeping standards. For an extreme example, if there were toxicity values for sugar and those values were used in the methodology, one would get high screening values because a person can ingest large amounts without adverse toxicity effects, but those surface levels would not be acceptable for an office environment. Practitioners need to be aware that environmental samples that are below health-based screening may still require action to comply with good work practices and housecleaning standards.

5.4 Uncertainty Analysis

All health risk assessments are subject to uncertainty and variability. As described in chapter 4, a key concept for users of TG 312 to understand is that there are significant uncertainties associated with the estimation of dermal toxicity criteria using this method. Some aspects of dermal toxicity are unique to this route of entry, and the resulting calculated risks are highly dependent on the parameter choices and toxicity value extrapolations made for this route of exposure. Accurate estimation of administered dose to the skin is problematic; moreover, accurately estimating the absorbed dose from that administered dose compounds the uncertainty. In addition, any time an adjustment is made from the 100 percent absorption assumption of the oral toxicity value, the dermal value tends to be "more toxic" per unit dose. These facts often increase the uncertainty for risks calculated for the dermal pathway.

Table 5-1 lists some of the major uncertainties associated with this methodology. Details on uncertainty and assumptions associated with each exposure factor are described in chapters 9 and 10 of this TG.

Table 5-1. Major Areas of Uncertainty

Issue	Uncertainty	Direction of Effect
Sampling Event		
Sampling variability and representativeness	The sample results may not accurately represent the areas from which they were collected. In addition, any type of sampling is subject to variability.	Varies
Sampling of porous or semi-porous surfaces	The method used to estimate the SWSLs was developed for nonporous surfaces; it is not valid for samples collected from porous or semi-porous surfaces.	Varies
Adjustment for sampling efficiency	The target surface loadings are adjusted down by 0.50 for organics and 0.75 for metals to account for wipe sampling efficiency.	Overestimates
Exposure to other substances that were not sampled	Exposed office workers may be exposed to additional substances that may potentially cause adverse health impacts, but the substances are not analyzed during wipe sampling.	Underestimates
Exposure Assessment		
Exposure from incidental ingestion	The screening values are based on fingertip-biting behavior which results in higher daily exposures due to default frequency on 27 events per day.	Overestimates
Contact frequency with surface	No office-specific data is available; therefore professional judgment is used to select a default value of four events/day.	Varies
Fraction of skin surface area that contacts surface	Limited actual data is available; therefore professional judgment is used to select a default value of 30%.	Overestimates
Fraction of chemical transferred from surface to skin	Limited actual data is available; therefore professional judgment is used to select a default value of 6.3%.	Varies

Table 5-1. Major Areas of Uncertainty (continued)

Issue	Uncertainty	Direction of Effect
Exposure Assessment		
Potential exposures to sources other than surface contamination	The screening values only apply to the exposures associated with surface contamination, so other sources would have to be evaluated and appropriately considered for a total risk estimate.	Underestimates
Toxicity Assessment		
Extrapolation of dermal toxicity from ingestion toxicity values	There is limited data available concerning the relationship between absorbed dose and dermal exposure. Anytime an adjustment is made from the 100%-absorption assumption of the oral toxicity value, the dermal toxicity value tends to be "more toxic" per unit dose.	Overestimates
Multiple chemical exposure	Screening level values are calculated on a single chemical. Additive acceptable risks may combine to create an unacceptable total risk.	Underestimates

CHAPTER 6
SURFACE WIPE SCREENING LEVELS FOR NONPOROUS SURFACES

This chapter provides the methods used to calculate health-based SWSLs for nonporous surfaces. These levels are calculated by selecting target levels for carcinogenic risks and noncancer hazard indices and rearranging the equations identified in this TG to solve for the target contaminant surface loading (C_s).

6.1 General Process

The general process for deriving a substance-specific SWSL is as follows:

- Step A: Calculate contaminant surface loading (C_s) based on carcinogenic effects.
- Step B: Calculate C_s based on noncancer effects.
- Step C: Compare values calculated from steps A and B and select lower value.
- Step D: Calculate target surface wipe level (C_{wipe}) using value selected in step C.
- Step E: Compare C_{wipe} to the analytical DL of the substance. If C_{wipe} is lower than the DL, set DL as the screening level.

Table C-1 in appendix C lists the screening levels recommended for this TG. This list excludes VOCs which are better characterized by taking air samples. If the SWSL for a substance is not available, the risk assessor will need to derive an SWSL by using the steps outlined in this paragraph. It should be noted that exceeding a screening level is not automatically associated with an unacceptable health risk, but further evaluation may be required. For example, the risk assessor may quantify health risks using the methods identified in chapter 5 and site-specific exposure conditions.

6.1.1 Step A: Calculate C_s Based on Carcinogenic Effects

A screening level based on carcinogenic effects needs to be calculated if the substance is a carcinogen. This is distinguishable from when a substance has no toxicity data from which to estimate carcinogenicity or the substance has not yet been assessed for carcinogenicity. These latter cases are considered data gaps.

The screening level based on carcinogenic effects is calculated by substituting all input equations into equation 6-1 and solving for C_s (equation 6-2). Exposures from incidental ingestion are based on fingertip-biting habits that result in higher average daily exposures because of the higher contact frequency when compared to other types of mouthing behavior (see paragraph 10.3.2). Table 6-1 identifies the parameters and values used in equations 6-1 and 6-2.

Equation 6-1

$$TR = \left[CSF_d \cdot \left(\sum (SA \cdot Fd) \cdot FT_{ss} \cdot C_s \right) \cdot \frac{ABS_d \cdot EV_{derm} \cdot EF \cdot ED \cdot 10^{-3}}{BW \cdot AT} \right] +$$
$$\left[CSF_o \cdot (SA \cdot Fd \cdot FT_{ss} \cdot C_s) \cdot (F_f \cdot FT_{SM}) \cdot \frac{EV_{ing} \cdot EF \cdot ED \cdot 10^{-3}}{BW \cdot AT} \right] + \left[CSF_{inh} \cdot \frac{(f_{resp} \cdot C_s \cdot 10^4 \cdot A_s \cdot R)}{V \cdot (\lambda_{dep} + \lambda_a)} \cdot \frac{IR_{inh} \cdot ET \cdot EF \cdot ED \cdot 10^{-3}}{BW \cdot AT} \right]$$

Equation 6-2

$$C_s = \left(\frac{TR \cdot BW \cdot AT}{\left(\left(CSF_d \cdot \sum (SA \cdot Fd) \cdot FT_{ss} \cdot ABS_d \cdot EV_{derm} \right) + \left(CSF_o \cdot (SA \cdot Fd \cdot FT_{ss}) \cdot (F_f \cdot FT_{SM}) \cdot EV_{ing} \right) + \left(CSF_{inh} \cdot \frac{f_{resp} \cdot 10^4 \cdot A_s \cdot R}{V \cdot (\lambda_{dep} + \lambda_a)} \cdot IR_{inh} \cdot ET \right) \right) \cdot \left(EF \cdot ED \cdot 10^{-3} \right)} \right)$$

6.1.2 Step B: Calculate C_s Based on Noncancer Effects

Screening levels based on noncancer toxicity endpoints are calculated by inserting input equations into equation 6-3 and solving for C_s (equation 6-4). Parameters and input values are defined in table 6-1.

Equation 6-3

$$THI = \left[\sum (SA \cdot Fd) \cdot FT_{ss} \cdot C_s \cdot \frac{ABS_d \cdot EV_{derm} \cdot EF \cdot ED \cdot 10^{-3}}{BW \cdot AT \cdot RfD_d} \right] +$$
$$\left[(SA \cdot Fd \cdot FT_{ss} \cdot Cs) \cdot (F_f \cdot FT_{SM}) \cdot \frac{EV_{ing} \cdot EF \cdot ED \cdot 10^{-3}}{BW \cdot AT \cdot RfD_o} \right] + \left[\frac{(f_{resp} \cdot Cs \cdot 10^4 \cdot A_s \cdot R)}{V \cdot (\lambda_{dep} + \lambda_a)} \cdot \frac{IR_{inh} \cdot ET \cdot EF \cdot ED \cdot 10^{-3}}{BW \cdot AT \cdot RfD_i} \right]$$

Equation 6-4

$$C_s = \left(\frac{THI \cdot BW \cdot AT}{\left(\left(\frac{\sum (SA \cdot Fd) \cdot FT_{ss} \cdot ABS_d \cdot EV_{derm}}{RfD_d} \right) + \left(\frac{(SA \cdot Fd \cdot FT_{ss}) \cdot (F_f \cdot FT_{SM}) \cdot EV_{ing}}{RfD_o} \right) + \left(\frac{f_{resp} \cdot 10^4 \cdot A_s \cdot R \cdot IR_{inh} \cdot ET}{V \cdot (\lambda_{dep} + \lambda_a) \cdot RfD_i} \right) \right) \cdot (EF \cdot ED \cdot 10^{-3})} \right)$$

6.1.3 Step C: Compare Values Calculated from Steps A and B and Select Lower Value

If a substance is a carcinogen, the risk assessor should select the lower C_s value calculated from equations 6-2 and 6-4 as this provides for a more health-protective value, which is appropriate for screening evaluations. Toxicity data gap can preclude the calculation of C_s based on either carcinogenic effects or noncancer health effects. When this occurs and the risk assessor must default to one value as the target surface loading, the risk assessor should make a notation in the final recommended SWSL for that substance. There is no need to make a step C comparison when the substance is not carcinogenic.

6.1.4 Step D: Calculate Target Surface Wipe Level (C_{wipe}) Using Value Selected in Step C

To account for uncertainties in wipe sampling efficiency (paragraph 8.2), this TG recommends adjustments of 0.50 for organics and 0.75 for metals. Therefore, the target surface loading from step C should be adjusted to obtain a surface wipe level as shown below. Definitions and recommended values are presented in table 6-1.

To express the SWSL as a loading over the size of a sample area, multiply the loading estimated from equation 6-5 by the size of the sample area. For example, if the SWSL is 0.2 microgram per square centimeter (µg/cm^2), the SWSL for a 100 square centimeters (cm^2) sample size would be 20 µg/100 cm^2.

Equation 6-5

$$SWSL = C_s \cdot \eta$$

Table 6-1. Parameters and Values Used to Estimate Screening Levels in Equations 6-2 and 6-4

Parameter	Definition	TG 312 Reference	Value or Equation No.
TR	Target risk level (unitless)	Paragraph 6.2	10^{-4} to 10^{-6}
THI	Target hazard index (unitless)	Paragraph 6.2	1
ABS_d	Dermal absorption fraction (unitless)	Paragraph 10.2.2	Substance-specific
A_s	Source area (square meter (m^2))	Paragraph 9.2.3.6	5.5
AT	Averaging time (days)	Paragraph 10.2.7	Cancer: 25,550 Noncancer: 3,650
BW	Body weight (kilogram (kg))	Paragraph 10.4.6	70
C_s	Contaminant surface loading ($\mu g/cm^2$)		Cancer: Equation 6-2 Noncancer: Equation 6-4
CSF_d	Dermal cancer slope factor $(mg/kg/day)^{-1}$	USACHPPM SOP No. 39-01-03	Substance-specific
CSF_{inh}	Inhalation cancer slope factor $(mg/kg/day)^{-1}$	USACHPPM SOP No. 39-01-03	Substance-specific
CSF_o	Oral cancer slope factor $(mg/kg/day)^{-1}$	USACHPPM SOP No. 39-01-03	Substance-specific
ED	Exposure duration (year)	Paragraph 10.2.3	10
EF	Exposure frequency (days/year)	Paragraph 10.2.5	250
ET	Exposure time (hours/day)	Paragraph 10.4.3	8
EV_{derm}	Event frequency for estimating the dermal dose (events/day)	Paragraph 10.2.4	4
EV_{ing}	Event frequency for estimating intake from incidental ingestion (events/day)	Paragraph 10.3.2	27 (fingertip/nail biting)
Fd	Fraction of exposed skin surface area that actually contacts the contaminated surface (unitless)	Paragraph 9.2.1.2	Forearm: 1 Hand (palmar side): 0.30
F_f	Fraction of exposed skin that contacts the mouth (unitless)	Paragraph 9.2.2.5	0.08
f_{resp}	Fraction respirable (unitless)	Paragraph 9.2.3.3	0.1
FT_{sm}	Fraction of substance transferred from skin to mouth (unitless)	Paragraph 9.2.2.6	0.4
FT_{ss}	Fraction transferred from the surface to the skin (unitless)	Paragraph 9.2.1.3	0.063
IR_{inh}	Inhalation rate (cubic meters (m^3)/hour)	Paragraph 10.4.2	0.833
λ_a	Air exchange rate (1/hr)	Paragraph 9.2.3.7	1.08
λ_{dep}	Deposition loss rate (1/hr)	Paragraph 9.2.3.4	3.0
η	Surface wipe sampling removal efficiency (unitless)	Paragraph 8.2	Metals: 0.75 Organics: 0.50
R	Resuspension rate (1/hr)	Paragraph 9.2.3.2	1.8E-03

Table 6-1. Parameters and Values Used to Estimate Screening Levels in Equations 6-2 and 6-4 (continued)

Parameter	Definition	TG 312 Reference	Value or Equation No.
RfD_d	Dermal reference dose (mg/kg/day)	USACHPPM SOP No. 39-01-03	Substance-specific
RfD_i	Inhalation reference dose (mg/kg/day)	USACHPPM SOP No. 39-01-03	Substance-specific
RfD_o	Oral reference dose (mg/kg/day)	USACHPPM SOP No. 39-01-03	Substance-specific
SA	Exposed skin surface area per event (cm^2)	Dermal: Paragraph 9.2.1.1 Ingestion: Paragraph 9.2.2.1	Forearms: 873 Hands (palmar side): 326
V	Room volume (m^3)	Paragraph 9.2.3.5	12
SWSL	Surface wipe screening level ($\mu g/cm^2$)		Equation 6-5
10^{-3}	Units conversion from µg to milligram (mg)		
10^{-4}	Units conversion from cm^2 to m^2		

6.1.5 Step E: Compare C_{wipe} to the Analytical Detection Limit of the Substance

The final step involves comparing the target surface wipe sampling level, C_s, to the substance's analytical DL or practical quantitation limit (PQL) (hereafter referred to as DLs). Due to varying wipe areas, which may not be known to the laboratory, DLs and PQLs (and analytical results) are typically reported in units of mass per wipe (for example, microgram per wipe (µg/wipe)). To be able to compare DLs to estimated health-based levels derived from step D, the DLs need to be converted to units of mass per area (for example, $\mu g/cm^2$) by dividing by the size of the wipe area.

For this TG, DLs were converted to units of mass (µg) per 100 cm^2 to be consistent with the wipe sampling area recommended in USACHPPM SOP No. DEHE-03-006 (USACHPPM 2006a). Appendix D lists DLs in units of mass per wipe, and appendix C, which lists the final SWSLs, contains the DLs in units of mass per area (µg/100 cm^2). The DLs listed in appendices C and D are limits that can reasonably be expected to be achieved by a capable laboratory using the analytical method specified in appendix C. Lower DLs are likely achievable in many cases. When it is necessary to decrease the limits to meet substance-specific SWSLs, the laboratory should be consulted to determine whether DLs will be low enough to meet the SWSL criteria.

After ensuring comparable units, compare the calculated SWSL from step D to the DL. If the calculated SWSL from step D is lower than the DL, then set the DL as the SWSL. A notation should be made for that substance to indicate the SWSL is not health-based but limited by

technological feasibility. This will provide additional information for risk managers to make risk management decisions. It is important to note that analytical DLs vary by laboratory; therefore, if a listed SWSL is currently based on the substance's analytical DL, risk assessors should consider the following:

- Is the laboratory providing the sample results capable of lowering the PQL/DL listed in appendix D?

- Is the "new" DL lower than the health-based, value-calculated SWSL?

6.2 Target Levels

For known or suspected carcinogens, the USEPA National Contingency Plan (NCP) states that exposure levels which correspond to an individual's excess upper-bound lifetime cancer risk of between 10^{-4} to 10^{-6} are considered acceptable for the remediation of hazardous waste sites (Title 40, Code of Federal Regulations (CFR), Section 300.430 (40 CFR 300.430), 2008). This upper-bound lifetime cancer risk range has been adopted by other agencies, both Federal and state, for making environmental risk management decisions. For screening evaluations, the more conservative limit of 10^{-6} is often used as the target level (TL) from which media-specific screening levels are derived for both residential and worker exposures (USEPA 2003a).

In contrast to carcinogens where the acceptable TL may be traced to a regulation, there is no similar TL for evaluating noncancer health effects. However, since noncancer effects are based on the concept of a threshold dose below which no adverse health effects are expected to occur, estimated hazard indices are often compared to a TL of 1. A TL of 1 is often used to develop media-specific screening levels based on noncancer effects (see, for example, USEPA 2003a).

Surface wipe screening levels for office worker exposures to indoor surface contaminants presented in appendix C are based on a target cancer risk level of 10^{-6} and a target hazard index (THI) of 1. Risk assessors and risk managers desiring surface wipe levels based on target cancer risk levels of 10^{-4} and 10^{-5} are encouraged to contact USACHPPM.

As noted earlier, SWSLs assume conservative exposure assumptions to provide protective screening levels; therefore, exceeding an SWSL signifies that there may be a potential for health effects. If this occurs, the risk assessor has the option of performing a site-specific risk assessment using the methods presented in chapter 5 and modifying input parameters that may be more reflective of site-specific conditions.

6.3 Substances with Existing Surface Wipe Standards and Recommended Levels

Standards for surface levels of contaminants exist both as enforceable levels published by a Federal or state agency and nonenforceable guidelines that may have been established for the purpose of assessing potential health risks from a specific incidence (for example, the World Trade Center (WTC)). This section examines known surface wipe levels and examines whether they are applicable for the purposes established in this TG.

6.3.1 Lead

The USEPA provides two types of standards for evaluating exposure to lead in dust: *hazard levels* intended for risk assessment purposes and *clearance standards* for evaluating the "effectiveness of cleaning following abatement" (Federal Register 2001). Final hazard and clearance levels for floors and interior window sills are the same, at 40 micrograms per square foot (µg/ft^2) and 250 µg/ft^2, respectively. These levels correspond to a 5 percent or less probability of a child's blood lead level exceeding 10 micrograms per deciliter (µg/dL), which was the hazard standard used to establish acceptable lead standards (Federal Register 2001). The USEPA also does not distinguish between bare and carpeted floors, pointing to the lack of studies to support a finding that exposure to carpeted floors poses a different health risk from exposure to floors made of other material (Federal Register 2001). Specifically, the USEPA noted the percentage of children whose BLL exceeded 10 µg/dL was comparable for carpeted and noncarpeted floors (Federal Register 2001).

The U.S. Department of Housing and Urban Development (USDHUD or HUD) has adopted the USEPA dust lead standards for clearance and risk assessment purposes and also provides screening levels of 25 µg/ft^2 and 125 µg/ft^2 for floors and interior window sills, respectively (24 CFR 35, Subpart R, 2008.). While many states have also adopted the USEPA surface wipe standards for lead, some states have opted for more stringent levels. For example, Washington State's clearance standard for lead is 20 µg/ft^2, half of USEPA's current standard (Washington State Department of Health (WSDOH) 2005).

The USEPA's lead standards are intended to protect children from potential developmental effects. For adults, the agency suggests using a model that estimates the fetal blood lead concentration in exposed women to protect fetuses and neonates (USEPA 2003d). However, because the Adult Lead Methodology was developed for lead exposure from incidental soil ingestion, the model cannot be used or easily modified for this TG.

To address the lack of noncancer toxicity data from which a lead SWSL can be derived, the USEPA's floor dust standard of 40 µg/ft^2 (4.3 µg/100 cm^2) is used to evaluate office worker

exposures because office workers may be comprised of child-bearing-aged women. It should be recognized that USEPA's lead standards were developed based on the behavior of children 1 to 2 years old who have a higher level of mouthing activity (USEPA 1998a). Therefore, the lead standard of 40 $\mu g/ft^2$ may be "too protective" of fetuses and neonates who are exposed indirectly through their mothers' exposure patterns, which most likely consists of less hand-to-mouth events than would occur with young children.

6.3.2 Polychlorinated Biphenyls

The USEPA also provides cleanup levels for PCBs in different media, which include nonporous surfaces (USEPA 2005b). These cleanup levels consider use of the property after cleanup, characterized as "high-occupancy" or "low-occupancy" areas (USEPA 2005b). Examples of high-occupancy areas are residences, schools, and single- or multiple-occupancy, 40-hours-per-week workstations. By contrast, low-occupancy areas primarily involve industrial uses such as exposure while working in an electrical substation or an electrical equipment vault (USEPA 2005b).

The recommended PCB cleanup level for nonporous surfaces and high-occupancy use is ≤ 10 $\mu g/100\ cm^2$ and applies to total PCB concentrations, not individual Aroclors (USEPA 2005b). Rather than adopt the total PCB cleanup level for the two Aroclors identified in table 2-1, substance-specific SWSLs are calculated for Aroclor 1016 and Aroclor 1254. If evaluating data for total PCB, the USEPA PCB cleanup standard of 10 $\mu g/100\ cm^2$ would be appropriate for office worker exposures to nonporous surfaces.

6.3.3 Beryllium

In 1999, the U.S. Department of Energy (USDOE or DOE) promulgated an agency rule to reduce the incidence of chronic beryllium disease among workers exposed to beryllium at DOE facilities (Federal Register 1999). The rule also provided for a removable surface level of 0.2 $\mu g/100\ cm^2$ for beryllium-contaminated items before they are released to the general public (10 CFR 850.31, 2007). A closer assessment of the derivation of this standard suggests it is limited to exposures from inhalation of resuspended beryllium from the contaminated surfaces (Federal Register 1999); therefore, this standard was not used for this TG.

6.3.4 Other Surface Standards or Guidance

In response to the attacks on the WTC and in support of the WTC Dust Cleanup Program, a task force was formed to select contaminants of concern and develop health-based benchmarks for exposure to indoor air and settled dust (Contaminants of Potential Concern (COPC) Committee

of the WTC Indoor Air Work Group (IAWG), USEPA Indoor Air Task Force (COPC Committee of the WTC IAWG 2003; USEPA 2005c)). These benchmarks were used to determine if cleanup of residences was needed and, if so, to verify that the cleanup methods were effective. A brief summary of the method used to derive health-based benchmarks is presented in appendix B.

Since the health-based benchmarks are not enforceable standards but guidelines, they were not adopted as SWSLs for this TG even though health-based benchmarks are available for metals, dioxins, and polycyclic aromatic hydrocarbons (PAHs). There are two main reasons for this decision. First, the health-based benchmarks were developed specifically to address residential exposures, and residents have significantly different exposure conditions from those of office workers. In addition, the methods used to develop the health-based benchmarks are different from those presented in this TG; therefore, adoption of the health-based benchmarks could result in inconsistencies with values developed using the methods presented in this TG.

Some states have developed guidance that includes limited surface wipe levels for the cleanup of former methamphetamine laboratories. For example, as noted above, the WSDOH lead wipe standard is 20 $\mu g/ft^2$. Although the methods used to derive these cleanup levels are not always clearly defined, it is evident that the cleanup levels are intended to protect residential populations. Since the SWSLs presented in this TG are intended for office exposures, surface wipe levels published by the states were not used. Generally, however, this TG does not recommend the adoption of state surface wipe cleanup levels to avoid potentially conflicting guidance. The risk assessor should be aware that these cleanup levels may be enforceable under state law and, depending on the jurisdiction of the site being evaluated, the risk assessor may be required to comply with state standards.

PART II
SITE-SPECIFIC ASSESSMENT APPROACH: FOR USE BY EXPERIENCED RISK ASSESSORS

CHAPTER 7
CONTACT SURFACE CHARACTERISTICS

To better characterize exposure to surface contaminants, it is necessary to understand how surface characteristics may affect exposure. This chapter explores factors that may have an effect on the transfer of substance from the contact surface to another medium (for example, wipe or skin) or resuspension of settled particles from the surface into the ambient indoor air. Paragraph 7.6 discusses surface types applicable to the assumptions used in this TG.

7.1 Surface Roughness

Surface roughness describes the texture, not the physical condition (for example, crack), of the surface. Although surface roughness may be quantitatively defined, when discussed in context of exposure to indoor surfaces, it is merely used as a descriptive term. For instance, carpet is usually described as having a rough surface while glass and vinyl provide examples of smooth-surfaced media (see Brouwer et al. 1999; Rodes et al. 2001).

Generally, as surface roughness increases, so does the surface area, which results in higher surface loading when compared to smoother surfaces. At the same time, rough surfaces are more efficient at trapping small particles or spills, which has a series of consequences for exposure assessment purposes. First, it makes sampling or remedial efforts more difficult. Sample results may underestimate potential exposure as some of the "trapped" substances could either dislodge from their location, or in the case of semi-volatiles, be released into the air over time. Second, trapped particles are less likely to be transferred to the skin from casual contact. One study reported significantly reduced transfer of house dust from carpet to the hands compared to transfer from smooth surfaces such as stainless steel and vinyl (Rodes et al. 2001). The authors attributed the decreased dust transfer to the carpet's roughness, which reduced the contact area, and to the increased static charge in the carpet fiber (Rodes et al. 2001). Due to these differences, it is important to select values that are representative of the exposure scenario. Values from smooth-surfaced experiments could overestimate EPs for exposure to rough surfaces and vice versa.

7.2 Porosity of Contact Material

Porosity is expressed as the fraction of space in the bulk volume of the material. Although this parameter is easily measurable for soil, it is much more difficult to measure for synthetic material. Generally, as the void to volume ratio increases, so does the porosity, and the surface is said to be more permeable. Therefore, porosity has a greater effect on liquid or "film-type" contaminants.

Porous surfaces of the type normally encountered indoors can usually be described as having a rough surface as well, and the two terms have been used synonymously (see Chavalitnitikul and Levin 1984). Since the effect of porosity on particles is less significant than surface roughness, using the terms interchangeably when discussing particle contaminants is probably acceptable. However, for liquid and film-type contaminants, porosity should be distinguished from the surface's roughness because contaminants in these forms are able to permeate deeper than the surface of the contact material, some of which may be released over time. Wood and concrete are common examples of porous surfaces while glass and vinyl are examples of nonporous surfaces.

7.3 Surface Hardness

Surface "hardness" has been used to distinguish carpets from "hard" surfaces such as walls and countertops (USEPA 1997a; USEPA 2005c). Casual contacts with either surface type, whether the surface is "hard" or "soft," probably have little impact on the skin contact area. The effect may be more pronounced when pressure is applied to the surface. Whether the increase in skin contact area is comparable for the same incremental increase in applied pressure is unknown. Experimental studies usually describe test surfaces based on the characteristics identified above and not the hardness of the surface.

7.4 Composition of Contact Material and Surface Treatment

One lesser known surface characteristic that may impact contaminant concentration over time is the sorptive potential of the contact surface. For example, organic compounds such as pesticides are readily absorbed by plastic or laminated surfaces (see Gurunathan et al. 1998). However, release of the absorbed substance under the right conditions is expected to affect mostly the indoor air quality and not the amount available for skin contact. For substances bound in particles like dust, contact surface properties or surface treatments (for example, furniture polish) may cause the particles to "stick" to the surface, resulting in less resuspension from the surface (Ko and Burge 2004).

7.5 Surface Orientation

Surface orientation (for example, horizontal or vertical) affects both particle deposition onto the surface and likelihood of contact with the surface. For large particles that deposit by gravitational settling, more particles may be found on textured vertical surfaces than on smooth vertical surfaces. However, the effect of surface orientation appears to have little impact on particles that deposit by diffusion (see Thatcher et al. 2002). These considerations affect estimating the deposition of resuspended surface particles. For example, it is more likely for particles resuspended from a smooth, horizontal surface to redeposit back on that surface. By contrast, it may be more likely for particles resuspended from a smooth, vertical or inclined surface to redeposit on nearby horizontal or porous surfaces.

Surface orientation also affects the frequency of contact with the surface, depending on the exposure scenario being assessed. For example, an office worker's contact with non-horizontal surfaces, such as walls or sides of cabinets, is expected to be infrequent compared to that of a demolition worker who will probably have greater exposures from contact with non-horizontal surfaces. Consideration of contact surface orientation during the estimation of the contact event frequency is briefly discussed in paragraph 10.2.4.

7.6 Definition of Contact Surfaces for Technical Guide 312

To be commensurate with the surface sampling methods used by the USACHPPM DEHE (see chapter 8), the SWSLs and assumptions used to provide recommended model default parameters in this TG are based on surfaces that are smooth and nonporous. Examples of nonporous, smooth surfaces provided by the USEPA (2005b) include uncorroded metals, glass, glazed ceramics, impermeable polished stone such as marble or granite, and high density plastics such as polycarbonates and melamines that do not absorb organic solvents. The last example is more difficult to place in context with everyday exposures as such information may not be readily available from the manufacturer. In addition, many experimental studies currently do not discuss the sorptive potential of test materials but merely discuss the test surfaces used or provide general descriptions (for example, "flat") of the surface type (see Clothier 2000; Edwards and Lioy 1999). Due to limitations of experimental data, common flooring materials such as linoleum, vinyl, or laminate are treated as smooth, nonporous surfaces for this TG. Plastic flooring material, however, is not expected to be common in an office environment, which is the focus of this TG.

CHAPTER 8
SURFACE SAMPLING METHOD CONSIDERATIONS

There is a wide variety of available dust sampling methods. Various Federal agencies as well as states have published dust sampling methods and/or dust sampling guidance. Thorough reviews of dust sampling methods have been published (Lioy et al. 2002; McArthur 1992). The discussion of sampling methods in this chapter is limited to methods designed to sample nonporous surfaces using wipe media wetted with an appropriate reagent. Therefore, methods using dry wipe media (no wetting agent) and methods for sampling dust from rugs and carpets and other porous surfaces are outside the scope of this discussion.

8.1 Surface Sampling Methods

Nonporous surface sampling for dust primarily involves manual surface wipe sampling techniques. Unfortunately, there are several issues related to manual wipe sampling that can lead to inconsistent results and must be addressed, or at least acknowledged. One primary concern is the varying amounts of pressure placed on the wipe and surface while sampling, especially from user to user. This can lead to different collection efficiencies and, therefore, different analytical results. Another concern is the amount of wetting agent (if any) applied to the wipe. Different degrees of wetting, from dry wipes to wipes saturated with wetting agent, have been employed. Dry wipes may not have sufficient collection efficiency. However, a saturated wipe may drip wetting agent, potentially losing some of the collected contaminant with the droplets. The actual wiping technique (direction, number of passes over the wipe area, etc.) can also vary from user to user and method to method. In addition, the differences in the wipe sampling materials themselves can lead to sampling/collection inconsistencies. Many different wipe materials have been employed for wipe sampling of nonporous surfaces to include cotton balls, swabs, gauze pads, paper filters, tissues, and baby wipes (as cited in Lioy et al. 2002 and McArthur 1992). These concerns lead to the conclusion that standardization of the surface wipe collection methods is critical to acquiring reliable results that may be usable in assessing health risk. Fortunately, progress has been made in the standardization of manual wipe sampling methods.

In order to concentrate on developing a defensible, yet useable method for evaluating surface sampling results, this TG focuses on the surface sampling methods most commonly used by the USACHPPM DEHE. The USACHPPM DEHE method (SOP No. DEHE-03-006) addresses nonporous surface wipe sampling for a variety of organic parameters, as well as metals (USACHPPM 2006a). Appropriate wipe wetting agents are recommended for metals and each class of organic compounds. Assumptions used in this TG are generally applicable to results obtained using wetted wipe sampling media and manual wipe sampling techniques. However,

this TG should not be used to assess results obtained from other surface sampling methods, such as those using vacuum samplers, that are significantly different from manual wipe sampling methods. A description of the USACHPPM DEHE method follows below.

The USACHPPM DEHE method is based in large part on a series of ASTM wipe sampling standards (ASTM International 2003a, 2006a, and 2008). Therefore, this TG also specifically applies to data collected using these ASTM International procedures. The ASTM standards include procedures specifically for lead (ASTM 2003a), for a more complete list of metals (ASTM International 2008), and for organic compounds (ASTM International 2006a). Although each standard was written for a different parameter/analyte list, the general procedure, to include wipe pattern, is the same or similar for all the standards. The wipe sampling pattern employed is an overlapping "S" pattern (two different directions), followed by wiping the corners to ensure all areas within the template have been covered. When sampling wide, flat surfaces, the ASTM standards for collection of surface wipe samples require a sampling template to ensure consistency in the area (dimensions) sampled. Selection of an appropriate sampling area (dimensions) is also discussed and is based on the observed or expected amount of settled dust present.

Like USACHPPM, ASTM International has moved toward standardization of the wetting agents to be used for a particular parameter. For example, deionized water is recommended for sampling metals (ASTM International 2003a, 2008); for pesticides and PCBs, isooctane is recommended (ASTM International 2006a). The user-to-user variability in collection efficiency is addressed in the standards (to some degree) by recommending one person perform all wipe sampling at a particular site. Other important sampling considerations are discussed in the standards, to include selection of appropriate sample containers, minimization of contamination, and proper sampling documentation. Also of note is that ASTM International has published a standard for manufacture/selection of appropriate wipe materials (ASTM International 2003b). This standard discusses wipe materials specifically for lead sampling, but may be applicable, with proper method validation, to sampling for other metals. Standard ASTM E1792 specifies that a minimum of seven wipes be tested to establish background concentrations of lead. If wipes conforming to ASTM E1792 are used for other metals, it is necessary to repeat this for each manufacturer batch of wipes, because the manufacturer is unlikely to be controlling any contaminant but lead. Standard ASTM E1792 describes wipe material specifications for background levels of analyte, ruggedness, moisture content, size, thickness, mass, collection efficiency, and expected analyte recovery (ASTM International 2003b). Standard ASTM E1792 also specifies that the wipes be individually wrapped and pre-wetted (ASTM International 2003b). Table 8-1 summarizes USACHPPM, ASTM International and other important wipe sampling procedures (and related guidance documents).

In summary, although there are options for collecting dust samples from surfaces, manual surface wipe sampling methods are often the best option since they are relatively easy to use, fast, and inexpensive (supplies, labor). In addition, significant progress has been made to standardize the manual sampling procedures, resulting in more reliable data. Many of the methods in table 8-1 are acceptable for use and can be used in conjunction with this TG. However, the USACHPPM method and ASTM International methods (ASTM International 2003a, 2006a, and 2008) are recommended. The ASTM International standard covering the selection of wipe materials (ASTM International 2003b) is complimentary to the sampling methods and serves to add reliability to the wipe sampling results.

Those responsible for surface wipe sampling projects should work with the candidate laboratory during planning and well ahead of sampling. Specific analytical methods should be requested if applicable. Discussions with the laboratory should take place to ensure the proper sampling material and wipe wetting agent are used for the parameter of interest. Analytical method quantitation limit requirements and the desired reporting format should also be identified to the laboratory to ensure project requirements are met. Overall, the laboratory must have validated procedures for the specific compounds or elements of concern, the wipe material to be used, the required method, and the required analytical quantitation limits. In addition, if the project requires the performing laboratory to hold a particular certification and/or accreditation, this should be verified early in the planning process.

Table 8-1. Summary of Wipe Sampling Procedures and Guidelines

Agency/Entity	Method Citation/Name of Guidance	Reference	Comment
ASTM International	E1728-03 (or most recent revision)	ASTM 2003a	Designed for lead sampling, but also appropriate for other metals. Detailed method covers practices to standardize sampling.
ASTM International	D6966-08 (or most recent revision)	ASTM 2008	Very similar to ASTM E1728
ASTM International	E1792-03 (or most recent revision)	ASTM 2003b	Includes wipe specifications for background concentrations, moisture content, collection efficiency, etc. Can be extended to other metals.
ASTM International	D6661-01 (or most recent revision)	ASTM 2006a	

Table 8-1. Summary of Wipe Sampling Procedures and Guidelines (continued)

Agency/Entity	Method Citation/Name of Guidance	Reference	Comment
ASTM International	D7296-06 (or most recent revision)	ASTM 2006b	Dry wipe sampling procedure (beryllium compounds) for surfaces where wet wiping is not feasible. Examples include surfaces that may be damaged by the wetting agent or ones with significant levels of grease. ASTM International discourages the use of this method on surfaces where wet wiping is feasible.
CDC	Comprehensive Procedures for Collecting Environmental Samples for Culturing *Bacillus anthracis*	CDC 2002	Provides guidance and procedures for sampling, but cautions that there are no validated sampling methods specifically for *Bacillus anthracis* in environmental samples.
USACHPPM	SOP No. DEHE-03-006: Standing Operating Procedure (SOP) for the Collection of Surface Wipe Samples	USACHPPM 2006a	Covers sampling for a variety of organic compounds (including chemical agent) and metals. Based on ASTM standard.
USEPA	Toxic Substances Control Act (TSCA) Section 403: Sampling Guidance for Identifying Lead-Based Paint Hazards. Public Review Draft.	USEPA 1998b	Refers to ASTM E1728 for appropriate wipe sampling procedures.
USEPA	Residential Sampling for Lead: Protocols for Dust and Soil Sampling: Final Report.	USEPA 1995a	Procedure/wiping pattern similar to that described in ASTM E1728.
USEPA	Final Report. Sampling House Dust for Lead: Basic Concepts and Literature Review.	USEPA 1995b	Discussion of various dust sampling methods.

Table 8-1. Summary of Wipe Sampling Procedures and Guidelines (continued)

Agency/Entity	Method Citation/Name of Guidance	Reference	Comment
USEPA	Polychlorinated Biphenyls (PCBs) Manufacturing, Processing, Distribution in Commerce and Use Prohibitions (40 CFR 761)	40 CFR 761.123 (2006)	Definition of standard wipe test (for PCBs) is provided. A brief procedure is included. Hexane is the specified solvent.
USEPA	Field Manual for Grid Sampling of PCB Spill Sites to Verify Cleanup (EPA/560/5-86/017)	USEPA 1986	A brief surface wipe sampling method (PCBs) is discussed. Isooctane is identified as a suitable solvent.
USEPA	Verification of PCB Spill Cleanup by Sampling and Analysis (EPA/560/5-85/026)	USEPA 1985	A brief surface wipe sampling method (PCBs) is discussed. Hexane is listed as an appropriate solvent.
USEPA	A Literature Review of Wipe Sampling Methods for Chemical Warfare Agents and Toxic Industrial Chemicals	USEPA 2007a	Review and summary of wipe sampling techniques. Includes wipe materials and method, but with no specific sampling pattern.
DHHS (NIOSH)	Method 9100, Lead in Surface Wipe Samples	DHHS (NIOSH) 1994	ASTM E1728 is a significant improvement over this method. Includes wipe materials and method, but with no specific sampling pattern.
DHHS (NIOSH)	Method 9102, Elements on Wipes	DHHS (NIOSH) 2003a	Refers to ASTM E1728.
DHHS (NIOSH)	Method 9105, Lead in Dust Wipes by Chemical Spot Test (Colorimetric Screening Method)	DHHS (NIOSH) 2003b	Refers to ASTM E1728. Includes wipe materials and method, but with no specific sampling pattern.
OSHA	Evaluation Guidelines for Surface Sampling Methods. Report No. T-006-01-0104-M	OSHA 2007	Includes a discussion of surface sampling considerations
OSHA	Method ID-105: Inorganic Arsenic in Workplace Atmospheres	OSHA 1991	

Table 8-1. Summary of Wipe Sampling Procedures and Guidelines (continued)

Agency/Entity	Method Citation/Name of Guidance	Reference	Comment
OSHA	Method ID-121: Metal and Metalloid Particulates in Workplace Atmospheres (Atomic Absorption).	OSHA 2002a	
OSHA	Method ID-125G: Metal and Metalloid Particulates in Workplace Atmospheres (ICP Analysis)	OSHA 2002b	Employs a sampling pattern (concentric squares) different from the ASTM methods ("S" pattern).
OSHA	Method ID-145: Particulate Mercury in Workplace Atmospheres	OSHA 1989	
OSHA	Method W4001: Hexavalent Chromium	OSHA 2001	Employs the concentric squares sampling pattern.
OSHA	Method W4002: 1,6-Hexamethylene Diisocyanate	OSHA 2002c	Employs the concentric squares sampling pattern.
OSHA	OSHA TED-01-00-015, OSHA Technical Manual	OSHA 1999	Section II, chapter 2 includes materials and procedures for wipe sampling, with specific methods for isocyanates and aromatic amines, employing the concentric squares sampling pattern.

Legend:
CDC = Centers for Disease Control and Prevention
DHHS = (U.S.) Department of Health and Human Services
NIOSH = National Institute for Occupational Safety and Health
OSHA = Occupational Safety and Health Administration

8.2 Adjusting for Wipe Sampling Efficiency

Wipe samples used to determine total mass on the surface should ideally reflect 100 percent of what is on the surface. Studies aimed at evaluating the efficacy of first wipes show second wipes of the same area usually contain detectable concentrations of the surface contaminant (Wheeler and Stancliffe 1998; Lichtenwalner 1992). Lichtenwalner (1992) reported second wipes recovered an average of 55 percent of the amount detected in first wipes. Lichtenwalner did not specify the wipe sampling method used in his study but the described method is similar to the one prescribed by OSHA. According to Wheeler and Stancliffe (1998), even when following standard wipe procedures such as the OSHA method, the average concentration in second wipes

was still 40 percent of the amount detected by first wipes. However, employing a consistent sampling method is expected to reduce variability in wipe efficiencies caused by factors associated with choice of method (for example, wipe material, choice of solvent) and operator variability (for example, pressure applied).

8.2.1 Range of Wipe Sampling Efficiency

Due to the wide range of wipe efficiencies reported in the literature, it is necessary to consider the representativeness of those values for the purpose of this TG. For example, wipe efficiencies compiled by Sansone (1987) range from less than 10 percent to greater than 90 percent. However, much of the data presented by Sansone are dated, and many sampling methods used to estimate those efficiencies have since evolved. Therefore, while these data are useful for showing the general limitations of wipe sampling, they may not be appropriate for consideration of an adjustment factor for current wipe sampling methods. Additionally, in order to limit variations caused by choice of sampling method, only efficiencies reported for sampling methods similar to the USACHPPM DEHE method described above should be used. Since the USACHPPM DEHE method is only intended for nonporous, smooth surfaces, results reported by Lichtenwalner and Wheeler and Stancliffe are limited because they are averages of samples taken from different surface types which include porous surfaces. Wheeler and Stancliffe noted wipe sample results were most consistent for Formica® surfaces while painted metal surfaces provided the most variable results, which suggests less variability for nonporous, smooth surfaces than for porous surfaces. A review of the wipe efficiencies compiled by Sansone (1987) also shows comparatively greater efficiencies for wipes taken from nonporous surfaces than from porous surfaces. (Formica® is a registered trademark of the Diller Corporation, Cincinnati, Ohio.)

Another consideration is what the term "efficiency" entails as it may be confusing depending on context of the discussion. Experimental studies conducted to evaluate the effectiveness of wipe sampling methods usually refer to a removal efficiency that is the total efficiency resulting from both sample collection and laboratory analysis. By contrast, reports concerning the development of a new method may discuss each efficiency separately. For example, OSHA discusses a removal as well as an extraction efficiency in its guidelines for surface sampling methods (OSHA 2007).

For this TG, only removal efficiencies—also collection or sampling efficiency—should be considered for adjusting wipe sampling results. Many agencies have developed wipe sampling guidelines to ensure more reproducible results and refined these procedures over time to include recommendations from experimental studies. When following the ASTM standard, ASTM states a collection efficiency of greater than 75 percent "has been found" for metals such as lead collected from smooth, hard surfaces (ASTM D6966-08 (ASTM International 2008)). Therefore,

when using a wipe sampling procedure similar to the ASTM standard, such as the USACHPPM DEHE method, it is reasonable to expect a collection efficiency of at least 75 percent. As shown in table 8-2, experimental data support a removal efficiency of greater than 75 percent for wipe sampling of metals from smooth, nonporous surfaces. Although some of the sampling procedures used may have been refined since those studies were conducted, the majority of the collection efficiencies reported still exceed 80 percent.

Table 8-2. Wipe Efficiency Data for Metals Sampled From Smooth, Nonporous Surfaces

Source	Summary of Wipe Method[a]	Substance/ Surface Type	Mean Surface Landing	Mean Removal Efficiency
Reynolds (1997)	• OSHA Method • Whatman® #42, 12-cm filter paper wetted with distilled water[b]	• Lead (in household dust) • Linoleum	Per 225 cm^2 2.08 µg 3.44 µg 37.36 µg	81.6% 75.5% 89.3%
	• HUD Method • Alcohol-free commercial wipes, wetted with distilled water			89.9% 107.5% 108.9%
Chavalitnitikul and Levin (1984)	OSHA but used moist Whatman® #42 filter paper, cut to 10x10 cm instead of 7-cm diameter filter paper	• Lead oxide (<40 µm) • Formica®	Per 100 cm^2 58.0 µg 70 µg 590 µg 625 µg	91.3% 88.6% 89.6% 85.5%
	OSHA but used moist paper towel cut to 10x10 cm instead of 7-cm diameter filter paper		Per 100 cm^2 53.5 µg 65 µg 500 µg 541 µg	84.3% 81.6% 76.0% 74.0%
Dufay (2005)	• Wetted Ghost Wipes® as wipe media[c] • Similar procedure to ASTM standard for metals •100 cm^2 sample area	• Beryllium • Smooth glass surface	3.0 µg to to 0.0030 µg/wipe	85.9%
	• Wetted Whatman® #41 filter papers • Similar procedure to ASTM standard for metals • 100 cm^2 sample area			106.2%

Notes:
[a]An agency's procedure may have evolved since the study was performed. For example, the OSHA method used by Chavalitnitikul provided no procedural instructions (for example, pressure applied to wipe medium). Current OSHA guidelines specify that "firm pressure" be applied when the wipe medium is moved across the surface (OSHA 2007).
[b]Whatman® is a registered trademark of Whatman PLC, Kent, England.
[c]Ghost Wipes® is a registered trademark of Environmental Express, Mt. Pleasant, South Carolina.

Legend:
cm = centimeter
µg = microgram
µm = micrometer

For organic compounds, wipe sampling efficiency is less predictable because wipe sampling procedures are less consistent. In addition, while it is reasonable to assume the analytical efficiency approaches 100 percent for metals analysis, the same assumption cannot be made for organics because different analytical methods may be used depending on the organic compound. Therefore, for organics, the total efficiency is a combination of both the collection and analytical efficiencies.

Of the limited wipe efficiency data available, most are based on wipe sampling of lead, radioactive substances, or microorganisms, and very little data are available for organic compounds (see Sansone 1987). However, due to the greater variability in wipe sampling procedure and analytical methods, the overall removal efficiency is expected to be lower than for metals. To estimate an adjustment factor for organics, the OSHA guidelines for the development of surface sampling methods was used (OSHA 2007). These guidelines describe ideal sampling surfaces as "extremely smooth and nonporous" and recommend that the sampling method achieve an efficiency of at least 50 percent, which includes efficiencies due to sample collection as well as analytical recovery.

In summary, this TG recommends removal efficiencies of 75 percent and 50 percent for metals and organics, respectively. To account for wipe sampling efficiency, wipe sample results should be adjusted as follows in equation 8-1:

Equation 8-1

$$C_s = \frac{C_{wipe}}{\eta}$$

Where:

C_s = surface loading adjusted for wipe removal efficiency (μg/cm^2)
C_{wipe} = surface wipe sampling results from the laboratory (μg/cm^2)
η = surface wipe removal efficiency (metals = 0.75, organics = 0.50)

8.2.2 Uncertainties and Limitations

Risk assessors should consider the following uncertainties and limitations.

• Default removal efficiencies are reasonable as long as the wipe sampling method is consistent with the ASTM wipe sampling procedure. These removal efficiencies should not be used to adjust sampling results obtained using vastly different surface sampling methods such as

vacuum samplers. In addition, recommended adjustment factors are for wet wipes only. In some cases, dry wipes may be necessary, for example, to prevent damage to the wipe surface (Brisson 2006). Data suggest much lower collection efficiencies for dry wipes. Dry Ghost Wipes® used to sample for beryllium on smooth surfaces resulted in a mean collection efficiency of only 15.5 percent (Dufay 2005). Although dry Whatman® 41 filter papers produced a better collection efficiency of 43.3 percent, this was still lower than the 106.2 percent mean collection efficiency obtained using wetted filter papers (Dufay 2005).

• Trying to account for 100 percent mass assumes all mass is available for exposure. This assumption may seem unreasonable for long-term exposures because some mass is likely to be dislodged from the surface over time. Conversely, it could be argued that the dislodged amount is simply transferred to another surface where contact is equally likely. While little is known about degradation of substances indoors, the process is expected to be slower than degradation outdoors because substances are not exposed to natural elements such as sunlight.

• Solvents used during wipe sampling potentially remove more chemical from the surface than the amount that could be dislodged from either human contact or human activity. In addition, solvents could strip surface material, unintentionally including other substances in the wipe sample.

• Studies involving transfer of substances from the surface to hands indicate surface loading affects the amount transferred to the hands. For example, Fenske and Lu (1994) observed a decrease in transfer efficiency of chlorpyrifos from test tubes to the skin when surface loading was increased. The effect of surface loading on transfer to the skin suggests surface loading would also affect transfer to a wipe medium. However, Chavalitnitikul and Levin (1984) reported no significant difference in removal efficiencies for wipes of Formica® surfaces with lead oxide loadings ranging from 0.58 to 6.25 $\mu g/cm^2$. The authors noted, however, that the coefficient of variation was higher for samples taken from surfaces with a lower surface loading. Another study involving lead sampling of linoleum surfaces also showed no major difference in removal efficiencies for surface loadings ranging from 0.0092 to 0.17 $\mu g/cm^2$ when either the OSHA or HUD wipe sampling method was used (Reynolds 1997). Contrary to expectations, wipes of surfaces with the highest lead level also produced the highest removal efficiencies. Despite these findings, results from Chavalitnitikul and Reynolds do not conclusively show that surface loading has little effect on wipe removal efficiency because their studies are limited to lead. Additionally, it is unknown whether surface loadings employed in these studies are representative of actual exposures. If surface loading is a factor, adjustment factors may need to be distinguished for wipes taken before and after remediation.

CHAPTER 9
DETAILED OFFICE WORKER EXPOSURE ASSESSMENT

Selecting the exposure scenario is a first step in determining the appropriate exposure parameters to be used for assessing direct and indirect exposures to surface contaminants. This is important because factors such as skin surface area exposed or contact frequency are affected by age and type of activity patterns.

9.1 Exposure Scenario Identification

In this TG, exposure assumptions are provided only for an adult office worker population. Limiting the scope permits focus on developing a defensible methodology that can easily be modified for other exposure scenarios. However, changes should only be made by skilled risk assessors who understand how exposure concentrations are used in the effects assessment. The following paragraphs discuss some specific populations who may come in contact with indoor surface contaminants.

9.1.1 Office Workers

For the purposes of this TG, office workers are those whose job functions involve mostly sitting at a desk. This group of workers is expected to come in frequent contact with both porous (for example, fabric-covered chairs) and nonporous surfaces (for example, computer components or desktop surfaces) while they are in the office. This TG provides exposure information only for full-time workers. Exposure estimates for full-time workers are presumably protective of part-time workers because full-time workers spend more time in the office, increasing the chance and duration of contact with contaminated surfaces. However, EPs are easily modifiable if site-specific assessments are desired.

9.1.2 Residents

Residents are more likely to come in contact with a greater variety of indoor surfaces and from different parts of the home. In addition, due to the more relaxed atmosphere of a home as compared to that of an office, residents of a home tend to dress more casually, resulting in a greater skin surface area available for contact. Residents are also more apt to engage in activities that involve direct contact with floor surfaces. Some examples include walking barefooted or sitting on the floor. This is especially true of children and infants, with the latter group spending most of their time close to the floor.

Due to the greater variety of surfaces that residents may encounter while in the home, EPs for residents are not included in this TG. Considerations for residential exposures should include, but not be limited to, children-specific EPs and contact with porous surfaces, such as carpets and upholsteries, because residents are more likely to come in direct contact with such surfaces while in the home.

9.1.3 Office Visitors

Visitors are another exposure group who may potentially encounter contaminated indoor surfaces. Visitors include not only those who enter the building as guests but those who enter the building for a limited purpose. Some examples include mail delivery personnel or persons who enter the building to attend a meeting. Because EDs and contact frequencies vary greatly for this exposure group, no EPs are provided in this TG. Concerns about this exposure group should be addressed on a site-specific basis. In addition, because exposure to visitors is likely to be short-term and/or sporadic and short-term dose-response information for assessing dermal exposure is currently lacking, evaluation of a visitor scenario is not recommended at this time.

9.1.4 Industrial Workers

Dermal exposure has long been recognized as a potential hazard among industrial workers. The American Conference of Governmental Industrial Hygienists (ACGIH®) first adopted the use of a skin notation in 1961 to identify liquids that could cause systemic effects when penetrated through unbroken skin (Boeniger 2003). Despite known dermal exposure hazards among industrial workers, this TG does not address those industrial workers whose jobs require them to work with chemicals or mixtures on a daily basis. Although these workers may contact surface contaminants while operating machineries or handling tools, their exposures should be assessed using established industrial hygiene methodologies in accordance with occupational health and safety guidelines and regulations. (ACGIH® is a registered trademark of the American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio.)

9.1.5 Demolition/Construction Workers

Demolition or construction workers may be exposed to surface contaminants when they enter a contaminated building. Exposure for this group of workers is expected to come primarily from inhalation of resuspended dust. Direct skin contact with surfaces is expected to be limited because of protective clothing such as gloves. In addition, compared to office or residential occupants, demolition and construction workers have a much shorter exposure period. Although general exposure assumptions presented in this TG may be modified to estimate exposures from short-term contacts, the lack of acute toxicity data precludes the production of meaningful

results. Therefore, until short-term toxicity data for evaluating dermal exposures are available, evaluation of a demolition or construction worker scenario is not recommended at this time.

9.2 Estimating Exposure to Surface Contaminants

Table 9-1 summarizes the pathways identified as possible routes of exposure to surface contaminants. Even though four potential pathways have been identified, only three are considered in this TG. The reasons for eliminating discussion of the fourth pathway are discussed in the respective subsections below.

Table 9-1. Possible Routes of Exposure to Surface Contaminants on Nonporous Surfaces

Exposure Pathway	Evaluated in TG 312?
Direct dermal contact with surface contaminants	Yes (See paragraph 9.2.1.)
Incidental ingestion of surface contaminants	Yes (See paragraph 9.2.2.)
Inhalation of resuspended surface contaminants	Yes (See paragraph 9.2.3.)
Inhalation of semi-volatiles sorbed to the surface	Yes (See paragraph 9.2.4.)

9.2.1 Direct Dermal Contact with Surface Contaminants

When a person performs an activity on a contaminated surface, some of the surface contaminants may be transferred to the skin. There are two ways to estimate dermal exposure. The first is to estimate a potential dose, which is the amount of chemical that is deposited on the skin (USEPA 1992b; USEPA 1997a; World Health Organization (WHO) 2004). Sometimes this is referred to as the deposited dose (Ness 1994). To avoid confusion, this TG always refers to the amount deposited on the skin surface as the potential dose. The second method of estimating dermal exposure is via an absorbed dose, which is the amount of chemical absorbed through the skin. This is equivalent to the potential dose multiplied by a skin absorption factor.

Although the USEPA estimates dermal exposure by calculating an absorbed dose (USEPA 2004b), this TG estimates dermal exposure by first determining the potential dose for each contact event. Breaking the calculation steps down to the smallest unit permits easier model refinement to accommodate new data as they become available. For example, current dermal exposure models assume the skin serves as a barrier that keeps out chemicals and do not consider portal-of-entry effects (for example, hyperpigmentation). Thus there is an advantage to expressing the dermal exposure as a potential dose rather than an absorbed dose.

Ultimately, since TG 312 does not account for loss over time, whether calculating a potential dose or an absorbed dose is irrelevant because the estimated mass absorbed at the end of the day is the same. Nevertheless, there is still an interest in distinguishing the two so that correct terminologies for describing exposure are used.

For dermal contact with soil, the USEPA estimates a dermal dose using an adherence factor that is based on activity-specific data. Since no similar data is available for contact with indoor surfaces and wipe sample results are expressed as a contaminant surface load (for example, milligrams per square centimeter (mg/cm^2)), not concentration (for example, mg/kg dust), the dermal dose from exposure to surface contaminants is based on the number of contacts with a contaminated surface. This is first calculated by estimating the potential dermal dose for exposures from an event, which is then multiplied by the number of events per day (see paragraph 10.2). Calculating the potential dose based on exposures to an "event," as opposed to single contacts with the surface, avoids the difficulty of estimating the number of daily contacts office workers typically make with the surface. At this time, limited office-specific data prevents a comparison of the degree of substance transfer from different office activities. Therefore, for now, an office activity (or event) is used generically to refer to any day-to-day office activity where exposure to a contaminated surface may occur. The equation for estimating the potential dermal dose is as follows:

Equation 9-1

$$PD_{derm} = \left[\sum_{i=1}^{n} \left(SA_i \cdot Fd_i \right) \right] \cdot FT_{SS} \cdot C_s$$

Where:

PD_{derm} = potential dermal dose for each contact with a contaminated surface (µg)
SA_i = exposed skin surface area per event (cm^2)
Fd_i = fraction of exposed skin surface area that actually contacts the contaminated surface (unitless)
i = subscript used to distinguish different parts of the exposed body (hand, forearm)
n = total number of distinguishable exposed body parts (unitless)
FT_{SS} = fraction transferred from surface to the skin (unitless)
C_s = contaminant surface loading (µg/cm^2)

Equation 9-1 modifies May et al. (2002) where dermal exposure is expressed as the total skin surface area that contacts a contaminated surface per day (square meters per day (m^2/day)). The May et al. model was adapted from an earlier USEPA Region 3 guidance for assessing wipe samples, which was cited in a draft risk assessment report for non-liquid polychlorinated

biphenyls (NLPCBs) performed by Parsons Engineering Science, Inc. (1997). As discussed previously, the status of this guidance is unknown.

The parameters used to estimate the amount of surface contaminant that adheres to the skin are the same as the May et al. model although the values, as discussed below, are different. One minor change is the separation of different body parts to allow for the use of different Fd values for each part. A discussion of each parameter used to estimate the potential dose and the recommended values and limitations of those parameters follow below.

9.2.1.1 Skin Surface Area—Direct Contact with Surface

9.2.1.1.1 Surface area factors

The surface area parameter represents the amount of exposed skin available for dermal absorption, and is estimated by determining the skin surface area that comes in contact with the contaminated surface. Values of surface area are affected by physical characteristics (weight and height), gender, and age. Other factors, such as climate and type of activity, influence the kind of clothing worn. Having more clothing would limit the amount of skin surface area in contact with a contaminated surface. Even though some compounds may penetrate clothing, because this TG does not deal with bulk chemicals (for example, liquid spills) but rather with residue, the amount of chemical that penetrates clothing is expected to be minimal. In one case study prepared for the Office of Pesticide Non-Dietary Subcommittee, the study referred to proprietary data which showed measured transfer factors for single layer clothing were 100-fold lower than transfer factors measured for uncovered body parts (USEPA 1999).

9.2.1.1.2 Office workers

Typical attire in the office environment must be considered to determine which body parts are likely to be exposed to surface contaminants. Business attire tends to be more formal than what one wears at home because office workers generally do not wear shorts to work. Although some organizations have “dress down” days when an office worker may show up in shorts, such days are infrequent and therefore not factored into the surface area determination because this TG focuses on long-term exposures. Based on this reasoning, the body parts most expected to come in frequent contact with surfaces are the hands and forearms. This assumes the office worker is clad in short sleeves and is conservative, because in the wintertime exposed surface areas would be limited to the hands only. In addition, even though the entire forearm or hand may be exposed, entire bare body parts do not necessarily come in contact with contaminated surfaces. For example, an office worker may rest an arm on a tabletop or lay a hand over a mouse, but the

office worker generally will not roll an arm around the tabletop. Therefore, only the undersides of the forearms and hands were used to derive surface area values that reflect expected surface contact patterns. It was further assumed that both forearms and hands could simultaneously be in contact with contaminated surfaces.

9.2.1.1.2.1 Estimating forearm surface area

Forearm surface areas were obtained from the Exposure Factors Handbook (USEPA 1997c). Since the surface area and body weight are codependent variables, 50th percentile values were selected to correlate with the mean body weight (70 kg) that is typically used to assess health risks (USEPA 2004b; USEPA 1997c). Male data were used because men have a larger skin surface area than women, resulting in more conservative estimates. As the Exposure Factors Handbook provides only whole forearm surface area values, an adjustment factor of 66.7 percent, or two-thirds of the whole forearm surface area, was used to modify the forearm surface area. This adjustment factor accounts for the underside of the forearm as well as the "spread-out" effect of the arm when it is laid on a flat surface.

9.2.1.1.2.2 Estimating hand surface area (palmar side)

Palmar surface areas (wrist crease to fingertips) were obtained from the open literature rather than applying adjustment factors to the whole hand surface areas provided in the Exposure Factors Handbook. Adult surface areas were reported in two studies which evaluated dermal exposure to particles on surfaces. Edwards and Lioy (1999), estimating hand surface areas from photocopies of the left and right hands of 18 male subjects, reported a mean hand surface area of 163 cm^2 (total n = 36). This value was also the median hand surface area of the 18 men. Comparing this value to the median and mean whole hand areas reported in tables 6-2 and 6-4 of the Exposure Factors Handbook suggests the palmar surface area of one hand is about 33 percent (median) and 39 percent (mean) of the whole hand area. In another study, Rodes et al. (2001) reported a male hand contact area of 174 cm^2. Although Rodes et al. reported a higher male surface area than Edwards and Lioy, the Rodes et al. data was limited to a single measurement (that is, one subject, one hand only). Table 9-2 summarizes the recommended surface areas to be used for estimating an office worker's exposure to surface contaminants via direct dermal contact. Palmar surface areas were not adjusted for "spread-out" effect because values are based on actual measurements.

Table 9-2. Recommended Surface Areas for Estimating Direct Dermal Contact (Office Workers)

Body Part	Total SA (cm^2)	Adjustment Factor	Recommended SA (cm^2)
Forearm (both)[a]	1,310	2/3 (underside of forearms + "spread- out" effect)	873
Palmar side of hand (single)[b]	163	2 (to account for both hands)	326

Notes:
[a]Surface area for adult males, using 50th percentile values. Source: Table 6-2, Exposure Factors Handbook (USEPA 1997c).
[b]Edwards and Lioy (1999).

9.2.1.1.3 Uncertainties and limitations

The recommended surface areas for office worker exposures are intended to be conservative yet reflect somewhat realistic exposures. However, risk assessors should always check to ensure site-specific conditions are similar to those assumptions used to estimate the surface area. The following points address some known uncertainties and limitations concerning the use of the recommended surface areas.

• Although it is reasonable to assume only the office worker's hands and forearms will be exposed, one uncertainty comes from the assumption that both hands and forearms are simultaneously in contact with the surface. While this may occur on occasion, such as when the office worker is typing, it is probably more reasonable, especially for long-term exposures, to assume that either one or the other forearm/hand is in direct contact with the surface, such as when a person writing at a desk leans one arm on the surface while writing with the other hand.

• Conversely, assuming that only the hands and forearms are exposed underestimates the total surface area available for exposure if the office worker is wearing a skirt or dress since parts of the legs may be exposed to the chair surface.

• The surface area of the underside of the forearm was estimated using an adjustment factor because the Exposure Factors Handbook does not provide surface areas for fractions of a body part. The adjustment factor of two thirds of the whole forearm area was selected to provide a conservative estimate. It is likely that the fraction of the forearm actually in contact with a surface in the office is lower than two thirds.

• Recommended surface areas are intended to provide reasonable estimates of long-term exposures from daily contact with nonporous surfaces in the office; therefore, they may not be

appropriate for estimating short-term exposures. Risk assessors concerned about short-term exposures could consider site-specific factors to determine whether the exposed skin areas could be reduced or should be increased. Similarly, the recommended surface areas should not be used for other exposure scenarios without first considering whether the assumptions used in this TG are reasonable for other exposure scenarios. As discussed in paragraph 9.1, residents are expected to have a larger exposed skin area available for contact with surfaces than office workers.

• If the risk assessor wants to perform a probabilistic assessment, the risk assessor must consider the correlation between body weight and surface area when selecting input parameters and distributions.

9.2.1.2 Fraction of Skin Surface Area That Actually Contacts the Surface (Fd)

9.2.1.2.1 Contact area

The parameter, Fd, modifies the exposed skin surface area to reflect the area that actually contacts a surface. As shown in figure 9-1, even when the hand is laid flat on a smooth surface, only part of the hand actually touches the surface. In figure 9-1, the hand was laid on top of a copy machine without applying any pressure. Only the fingertips and base of the palm actually touched the glass surface.

Experimental data of hand presses on smooth surfaces show Fd is affected by surface loading, the number of repeated contacts, and the pressure applied (Brouwer et al. 1999; Rodes et al. 2001). For a single hand contact, Brouwer et al. observed an average exposed palmar side hand area of between 7 to 26.6 cm^2 (4 to 16 percent of the area) for mean surface loadings of 6 $\mu g/cm^2$ and 177 $\mu g/cm^2$, respectively. Measurements were taken from three volunteers who applied a constant pressure of 0.005 kilogram per square centimeter (kg/cm^2) to glass plates loaded with finely grounded Tinopal®, a fluorescent whitening agent. (Tinopal® is a registered trademark of Ciba-Geigy Corporation, Ardsley, New York.)

In another study, Rodes and his colleagues measured the actual contact area by asking four adult subjects to place a hand over the clean surface of a copy machine. Rodes et al. observed a mean actual contact area of 37.2 percent when a constant pressure of 5.4 kg was applied. Although Rodes et al. did not explain why this pressure was used, it has been suggested elsewhere that this force simulates the amount of pressure produced by a crawling infant or walking toddler (Lu and Fenske 1999). Rodes et al. also noted the percent contact area was comparable between male and female even though male volunteers had a larger hand area.

Rodes reported a higher hand contact area than Brouwer et al., which may be explained in part by the higher applied pressure used in the Rodes et al. study. A direct comparison of the pressures applied between both studies was not possible because Brouwer et al. did not indicate whether they used the whole hand area or the actual contact area to calculate the applied pressure of 0.005 kg/cm^2. However, using either hand area, Rodes' subjects still applied a comparatively greater pressure per cm^2 than Brouwer's subjects. Rodes reported a single hand contact area of 61.1 cm^2 and whole hand area of 174 cm^2. This amounts to a pressure of 0.088 or 0.031 kg/cm^2 (5.4 kg divided by the respective areas), which is at least six times higher than the pressure Brouwer used in his experiment. Although Rodes concluded applied pressure only had a "modest influence" on the contact area, the researchers still observed a 3 to 5 percent increase in contact area for each pound (0.5 kg) of force applied. This trend continued up to 16 lbs (7.3 kg).

Figure 9-1. Darkened Image of Hand to Accentuate Areas in Actual Contact with Smooth Glass

One other possibility as to why Rodes reported a higher percentage of exposed area than Brouwer involves the system used by Brouwer to measure the exposed area. The video imaging system used could potentially underestimate the exposed area for high surface loadings. If results were corrected to include false negatives, the reported exposed area of 62 cm^2 (Fd = 39 percent) after 12 contacts would increase to 95.2 cm^2 (Fd = 54 percent) for the high surface loading trial run. The authors thought it reasonable to expect the exposed area, after 12 repeated contacts, to range between 40 to 54 percent.

Work performed by Zainudin and Semple (2005) suggests the low exposed area is not unreasonable for contact with smooth surfaces. Zainudin and Semple applied 550 mg of powdered Tinopal® to an area 20 centimeter (cm) x 15 cm, and asked volunteers to press their hands for 5 to 10 seconds to the surface, which is comparable to Brouwer's contact time of 6 seconds. For a single contact, Zainudin and Semple reported a mean exposed area of 10 percent, which is similar to the values reported by Brouwer et al. A direct comparison of the applied pressure was not possible because Zainudin and Semple did not measure this parameter. The study by Zainudin and Semple is further limited because it is unclear how many subjects were involved although it is known the mean value was based on 3 to 5 measurements. In addition, Zainudin and Semple combined data for contacts with smooth surfaces and tools (pliers or screwdriver). Table 9-3 summarizes experimental results reported by Brouwer et al., Rodes et al., and Zainudin and Semple.

Table 9-3. Summary of Experimental Data on Actual Hand Area Exposed—Contact with Smooth Surfaces Only

Study	Surface Loading ($\mu g/cm^2$)	Measured Area (cm^2)	Percent of Exposed Area (%)	Number of Repetitive Contacts	Pressure Applied
Brouwer et al. 1999	6 177 177	7.0 26.6 61.9	4 16 39	1 1 12	0.005 kg/cm^2
Rodes et al. 2001	None	Not reported 61.1	37.2 (mean, n = 4) 35 (n = 1)	1 1	5.4 kg
Zainudin and Semple 2005[a]	1,830[b]	Not reported	10 34	1 6	Not reported

Notes:
[a]Data based on contact with smooth surface and tool (pliers or screwdriver)
[b]Estimated from data presented in Zainudin and Semple (550 mg solid and smooth area of 20 cm x 15 cm)

Brouwer et al. also observed the effect of contact time and frequency on the area exposed. For repeated surface contacts, Brouwer et al. reported an increase in hand contact area with increasing repetitions. For the higher surface loading trial run, the area exposed by the sixth contact was twice the exposed area of the single contact (about 33 percent of the exposed area). Zainudin and Semple reported a mean exposed area of 34 percent after six contacts. As for varying contact times, Brouwer et al. did not observe significant changes in exposed area between 3 seconds and 30 seconds.

Since no office activity-specific data are available, results from repeated contact studies were used to estimate Fd for typical office activities. As shown in table 9-3, Zainudin and Semple reported an Fd of 34 percent based on six consecutive contacts with smooth surfaces and tools. Brouwer et al. obtained similar results, reporting an Fd of 39 percent for 12 repeated surface contacts. Assuming Brower at al. corrected results for false negatives, the fraction exposed would increase to 54 percent.

For the purposes of this TG, a default value of 0.30 is recommended for evaluating office worker exposures from day-to-day office activities (for example, laying hand on table while reading, typing, etc.). This value was rounded down from the 34 percent (0.34) reported by Zainudin and Semple for six repeated contacts. Some factors were taken into consideration when rounding down this value. First, most surface contacts in the office do not involve hand presses. While occasional hand presses may occur, parameters selected for this TG are based on the most likely daily exposures because this TG focuses on evaluating potential health effects from long-term

exposures. Hand presses would probably not be considered normal day-to-day office exposures. Second, this TG currently considers only contacts with smooth, nonporous surfaces. Therefore, Zainudin's results, which included grasping tools, probably overestimates Fd from casual office contacts with surfaces. Lastly, unless the contaminated surface is loaded with a large amount of particles, the maximum Fd is probably much less than 50 percent for casual contacts.

Up until now, the discussion has focused on the hands. No data is available for estimating the Fd for the forearm. However, unlike the hand which is characterized by creases and joints, the forearm is smooth. Therefore, it is reasonable to assume 100 percent (that is, Fd = 1) of the forearm is in actual contact with the surface when placed on a smooth surface. Table 9-4 summarizes final Fd values to modify the forearm and hand areas to account only for the portions that contact the contaminated surface.

Table 9-4. Recommended F_d[1] Values for Office Workers

Body Part	Recommended Fd
Forearm	1
Palmar side of the hand	0.30
Note: [1]Fd = fraction of skin surface area that actually contacts the surface	

9.2.1.2.2 Uncertainties and limitations

Risk assessors should consider the following uncertainties and limitations with the assumptions used to derive recommended Fd values.

• Fd values provided for the palmar side of the hand are limited to application to smooth, hard surfaces only. Fd values for hand contact with soft surfaces (for example, carpet) would be higher.

• Values were derived for estimating long-term exposures. Users may need to reconsider Fd values for estimating short-term exposures.

• Fd values provided are limited to fine particles and should not be used for direct contact with liquids on the surface.

• Due to limited data available, the default Fd for the palmar side of the hand was not reduced below 30 percent. This fraction probably overestimates the area that actually comes in contact with the surface for normal office activities. One day-to-day office activity in which Fd may come close to 30 percent is talking on the phone (that is, the hand grasping the receiver). Recall,

however, that this TG deals with nonrenewable contamination and long-term exposures. Since phone receivers have a limited surface area, other surfaces such as desktops are the more likely office surfaces to consider for long-term exposures. The risk assessor could consider whether to adjust this parameter downward for site-specific studies.

9.2.1.3 Fraction Transferred from the Surface to the Skin (FT_{ss})

9.2.1.3.1 Background

The parameter, the fraction transferred from the surface to the skin (FT_{ss}), estimates the amount of surface contaminant transferred to the skin after contact with the surface. Depending on the objective of the experimental design, this parameter is sometimes referred to as "removal efficiency." For example, studies that observe the difference between surface sampling methods and the actual amount of surface residue "removed" by the hands often use the term "removal efficiency" to describe the FT_{ss} term used in this TG. To better present information on the parameter, FT_{ss}, this section is organized into three subsections: factors that affect FT_{ss}, methods of estimating FT_{ss}, and selection of FT_{ss} values based on assumptions used in this TG.

9.2.1.3.1.1 Factors that affect FT_{ss}

The amount of surface contaminant transferred to the skin is affected by numerous factors ranging from differences in experimental design to the degree of moisture on the skin (see table 9-5). For example, the type of solvent used has been demonstrated to affect the amount of chlorpyrifos recovered from the hands after surface contact (Fenske and Lu 1994). The same study showed prewashing with ethanol improved chlorpyrifos recovery from the hands. Although this method may improve contaminant recovery, prewashing with a solvent not normally found on the skin potentially results in more chlorpyrifos transferred from the surface to the skin. For example, Slayton et al. (1998) found hexane wipes picked up more contaminants than the amount that might be picked up by human skin. In a nonindustrial environment, the types of solvent found on the skin are most likely natural, such as sweat, oils secreted by the skin, and saliva.

Even though hexane may remove more surface contaminants than natural solvents on the human skin, variations in transfer efficiency may not be significant. Using vegetable oil to mimic human oil and saline solution to simulate human sweat, Slayton et al. (1998) observed PCB pickup efficiencies of less than 1 percent and about 2.5 percent, respectively, when compared to hexane wipes. Moisture level of the skin may have a more significant impact on the amount transferred from the surface to the skin. Clothier (2000) estimated comparable chlorpyrifos transfer efficiencies of 4.38 percent and 5.22 percent for hands wetted with saliva and water,

respectively. However, when no solvent was used, only 1.53 percent of the dry residue was measured on the hands. The significance of skin moisture level was also noted in studies involving particle transfer. Hands wetted with surrogate saliva picked up 67 to 71 percent more particles from stainless steel surfaces than dry hands (Rodes et al. 2001).

Table 9-5. Summary Of Factors that Affect FT_{ss} Values

Factor	Comments/Supporting Studies
Method of measuring amount transferred to the skin and experimental design	• Currently, there is no one protocol for measuring the transfer of surface residue to the skin. This makes comparison between studies difficult. • Use of a precleaned versus a "dirty" test surface may have an effect on the amount transferred to the skin.
Type of solvent used to recover amount transferred to the skin	• For hand-wash techniques, use of solvents improves surface contaminant recovered from the hands; however, an ideal solvent for one contaminant may not be the ideal choice for another. • Fenske and Lu (1994) showed time between contact and hand wash did not affect chlorpyrifos recovery when ethanol was used, but did affect chlorpyrifos recovery when isopropanol/water was used.
Skin moisture level and type	• Dampness of the skin affects the amount transferred. Damp skin picks up more residue/particles from the surface than dry skin. • Studies suggest the type of natural solvent is not a significant factor in contaminant transfer from the surface to the skin. • Transferability is also affected by contact surface moisture. Transferability is greater for wet surfaces (Ramwell et al. 2006).
Intensity of surface contact (for example, rubbing, pressure applied)	• Smudging, amount of pressure applied to the surface during contact, and the number of successive contacts may increase transfer. Contact with a clean surface may result in removal of contaminants already transferred to the hands (Brouwer et al. 1999).
Contaminant surface loading	• Increasing surface loading results in decreasing transfer efficiencies, which indicates a specific skin surface area is not a limitless receptor.
Contaminant type/formulation	• Transfer efficiency will be affected by the type of residue (for example, bound to dust, dried-on surface) on the surface. For pesticides, the formulation (for example, wetable powder, flowable) may also affect transfer efficiency (Fenske and Lu 1994). • Some compounds transfer better to the skin. The percentage of pyrethrin transferred was about two times higher than chlorpyrifos or piperonyl butoxide (Clothier 2000). Ramwell et al. postulated transferability is affected by a surface contaminant's octanol-water partition coefficient and less by its solubility. • Smaller particles are more likely to stick to the skin because of strong adhesive forces (Rodes et al. 2001). • One study involving microorganisms showed positively charged bacteria transferred more readily to other surfaces than gram-negative bacteria or viruses (Rusin et al. 2002). This study suggests transfer efficiency may be affected by the charge of the surface contaminant.
Surface contact time	• No significant change in transfer efficiency was observed between contact durations ranging from 3 to 30 seconds (Brouwer et al. 1999). The effect of a wider time range on the transfer efficiency is unclear. McArthur and Lees (1995) noted significant differences in mass transferred from a smooth surface for contact times ranging from 5 to 20 minutes; however, McArthur and Lees used oil as a test substance and a porous medium to collect oil from the surface. It is unknown whether the observations of McArthur and Lees could be applied to transfer of particles to the skin.

Another experimental factor that has a significant impact on measured transfer efficiencies is the degree of rubbing with a contaminated surface. This effect was noted by Slayton et al. (1998) who observed dry and oil-wetted wipes picked up less than 1 percent PCB with no rubbing and about 2 percent with rubbing. The effect was more pronounced when saline-wetted wipes were used; no rubbing removed 2.5 percent compared to 12 percent with rubbing (Slayton et al. 1998). In the Slayton et al. study, "no rubbing" conditions were intended to mimic casual surface contacts such as when a person supports his weight on one hand while picking up an object off the floor.

The effect of using a precleaned or new versus "dirty" test surface may also affect the fraction transferred. However, this cannot be verified because there are too many varying conditions between experimental designs to provide a meaningful comparison between existing studies. As an example, Lu and Fenske (1999), who did not preclean smooth furniture surfaces, reported a lower percentage of chlorpyrifos transferred to the hands than either Clothier (2000) (new sheet flooring) or Edwards and Lioy (1999) (precleaned polyethylene surface). However, Lu used different contact conditions and chlorpyrifos surface loading than either Clothier or Edwards and Lioy. A direct comparison of the results of Clothier to the results of Edwards and Lioy is similarly hampered by varying test objectives and conditions.

9.2.1.3.1.2 Methods of estimating FT_{ss}

In general, two types of data equivalent to FT_{ss} are reported in the literature. The first involves direct measurement of contaminant mass on the hands after surface contact. Transfer factors from these studies are derived by measuring the amount of contaminant on the hands using hand-wash or hand-wipe techniques and comparing the amount recovered to the total amount on the contaminated surface. A literature search for values using such experimental design uncovered data for only a handful of commonly used pesticides. These studies often refer to pesticides detected on the surface as a "residue" because pesticides are normally present only after pesticide application. While some studies used a clean test surface, others applied pesticides without precleaning the surface. Pesticide residue in the latter type of experiment would include pesticides adsorbed or absorbed into dust or other indoor particles in addition to a dried layer that may not be visible to the eyes.

The second type of data involves measurements using particles such as dust or ground-up Tinopal®. Since surface sampling results do not provide contaminant concentrations (mg of contaminant/mg dust) but surface loading (mg contaminant/surface area), use of this group of data requires some assumptions to relate the amount of dust/particles transferred to the amount of contaminant transferred from the surface to the skin. The simplest approach is to assume the contaminant is evenly distributed. This means the amount of contaminant transferred is relative

to the fraction of particle transferred to the skin, so the same transfer fraction is applicable. This is a fair assumption because environmental samples often assume concentration within each sample is evenly distributed. Bioavailability of the contaminant becomes an issue for compounds bound to particles. However, this affects availability of the contaminant for dermal absorption and not transfer of the contaminant from the surface to the skin.

9.2.1.3.1.3 Selection of FT_{ss} values based on assumptions used in this technical guide

Table 9-6 lists data from several studies that reported the fraction of contaminant transferred from smooth surfaces to the hands. The first rows of table 9-6 show results from studies that measured the amount of pesticides transferred to the hands after contact with an experimental surface. At first glance, values appear to vary widely, ranging from 0.69 percent (Lu and Fenske 1999) to 92.9 percent (Fenske and Lu 1994). However, as mentioned above, factors such as study objectives and measurement conditions do affect experimental outcome. For example, Ramwell et al. (2006) acknowledged results were higher than published data possibly because of the sampling technique employed. The test conditions from Ramwell et al. involved rubbing the entire tank surface for 3 minutes using methanol-washed cotton gloves. The authors' approach is not unreasonable since the study focused on measuring the transferability of pesticides from the surface of pesticide sprayers. Similarly, Fenske's data were derived from hands grasping test tubes while technicians rotated the test tube (Fenske and Lu 1994). In that study, the authors were interested in measuring the efficiency of hand-wash techniques.

Studies such as those from Ramwell et al. (2006) or Fenske and Lu (1994) are important because they help explain factors that affect transfer of surface contaminants to the hands. These factors must be considered when selecting a representative FT_{ss} value for the exposure scenario of interest. For office workers, FT_{ss} values should reflect casual contact with the surface; therefore, experimental values derived from vigorous rubbing are probably not appropriate. In addition, although not explicitly stated, many studies focused on a crawling infant as the likely receptor. Studies designed to mimic exposures to a crawling infant applied forces not normally associated with casual surface contacts. Although office workers may occasionally lean on a surface, thereby applying a larger force over the contact area, for evaluating long-term exposures, contacts should reflect those typical of daily routines when estimating long-term exposures.

Table 9-6. Summary of Experimental Surface-to-Hand Transfer Efficiencies for Particles and Pesticide Residues (Smooth Surfaces Only)

Study	Percent Transferred to Skin (%)	Average Surface Loading	Test Substance	Surface Type	Contact Conditions	Notes
Ramwell et al. 2006	25–85 (unwashed surface) 20–70 (washed surface)	5 mg/surface	Pesticide residue (sprayed on surface and air dried for 24 hours)	Polyethylene water tank (outer surface)	Methanol-washed cotton gloves, rubbed entire tank surface for 3 minutes	Ramwell et al. noted: • Transfer efficiency is compound-dependent. • Transfer efficiencies were higher than published data possibly because of sampling technique.
Fenske and Lu 1994	45.5[a] 54.7[b]	2,500 µg/42 cm^2 2,500 µg/42 cm^2	Chlorpyrifos (applied as liquid formulation and allowed to dry on surface of test tube, that is, dry residue)	Test tubes, SA about 42 cm^2	Hands grasped test tubes 10 times while technicians rotated tube	Ethanol was used as a hand-washing solvent to recover chlorpyrifos from the hands after surface contact. Fenske and Lu noted: • Prewashing hands with ethanol improved recovery of chlorpyrifos from the hands after surface contact.
	64.4[a] 60.8[b] 52.9[a] 87.6[a] 92.9[a]	2,500 µg/42 cm^2 2,500 µg/42 cm^2 250 µg/cm^2 25 µg/cm^2 2.5 µg/cm^2				10% isopropyl/water used as solvent to recover chlorpyrifos from the hands after surface contact. Fenske and Lu noted: • When surface loading was high (> approximately 1 µg/cm^2), transfer efficiency decreased. • Mass balance showed 37%–47% "remained" on the hands when washed with isopropanol/water, 0 and 1 hour after surface contact, respectively.

Table 9-6. Summary of Experimental Surface-to-Hand Transfer Efficiencies for Particles and Pesticide Residues (Smooth Surfaces Only) (continued)

Study	Percent Transferred to Skin (%)	Average Surface Loading	Test Substance	Surface Type	Contact Conditions	Notes
Clothier 2000	1.53 3.64 1.41	3.775 µg/cm^2 0.1064 µg/cm^2 2.215 µg/cm^2	Chlorpyrifos Pyrethrin I Piperonyl butoxide	New, vinyl sheet flooring	Single hand press (dry hand) (0.07 kg/cm^2, 1 second)[c]	Formulated pesticides were applied to surfaces and allowed to dry for 4 hours prior to testing. Double isopropanol-gauze wipe method was used to wipe residue from palms. Authors noted: • Wet hands removed about three times more than dry hands. • Wetness of saliva, not viscosity, etc., was a factor. • Transfer on day 1 was higher than subsequent days.
	4.38 8.89 2.64	3.775 µg/cm^2 0.1064 µg/cm^2 2.215 µg/cm^2	Chlorpyrifos Pyrethrin I Piperonyl butoxide		Single hand press (human saliva-wetted hand) (0.07 kg/cm^2, 1 second)[c]	
	5.22 11.87 2.95	3.775 µg/cm^2 0.1064 µg/cm^2 2.215 µg/cm^2	Chlorpyrifos Pyrethrin I Piperonyl butoxide		Single hand press (water-wetted hand) (0.07 kg/cm^2, 1 second)[c]	
Lu and Fenske 1999	0.69 (as percent of initial deposition)	1.79 µg/cm^2 (initial deposition) 12.4 ng/cm^2 (mean surface residue)	Chlorpyrifos	Smooth furniture surface (for example, (desktop)	10 hand presses (5.4 kg)	Data was adjusted for hand-wash removal (22%) and extraction (60%) efficiencies from previous study.
Edwards and Lioy 1999	45 14 66 100	<u>% Total Vol Distribution</u> 0.08 0.04 5 94	<u>Housedust</u> 0-2.5 µm 2.5-10 µm 10-50 µm 50-200 µm	Precleaned glass slides	Single hand press (15 lbs (6.8 kg), 5 seconds)	Transfer was measured using hand-rinse technique.
	42 29 43 21	<u>Initial Deposition</u> Not measured 0.09 µg/cm^2 0.12 µg/cm^2 0.06 µg/cm^2	<u>Housedust Followed by Pesticide Spray</u> Atrazine Diazinon Malathion Chlorpyrifos	Flat, polyethylene surface		

Table 9-6. Summary of Experimental Surface-to-Hand Transfer Efficiencies for Particles and Pesticide Residues (Smooth Surfaces Only) (continued)

Study	Percent Transferred to Skin (%)	Average Surface Loading	Test Substance	Surface Type	Contact Conditions	Notes
Brouwer et al. 1999	2 0.14	6 µg/cm² 177 µg/cm²	Pounded Tinopal®	Smooth glass	Single hand press (0.005 kg/cm², 6 seconds)	
Rodes et al. 2001	69 (dry) (58.2 to 76) >100 (damp) >100 (wet)	36.3 to 42.6 µg/cm² (dry) 23.8 to 32.0 µg/cm² (damp) 30.6 to 45.0 µg/cm² (wet)	Simulated dust (particle size < 80 µm	Stainless steel	Single hand press (5.4 kg)	Wet skin glistened slightly when exposed to light; damp skin did not. Rodes et al. noted: • Skin moisture level affects transfer to hands. • Smaller size fraction more likely to remain on the skin. • Hand movement (smudging) increased transfer by 60%.
Zainudin and Semple 2005	2.1 (0.3 to 4.3)	550 mg/300 cm²	Tinopal® powder	Smooth surface and tools (screwdriver or pliers)	Single hand press or held tools for 5–10 seconds	Zainudin and Semple did not separate results for hand presses with smooth surface and contact with tools. Zainudin and Semple also reported higher transfer efficiency (25 to 52%, mean of 38%) when measuring Tinopal® transfer from surface to hand, then to the face. Authors did not explain why results are different.
	39 (20 to 94)				Six hand contacts	

Notes:
[a]Time between skin contact and hand-washing to recover amount of chlorpyrifos transferred was less than 1 minute (Fenske and Lu 1994)
[b]Time between skin contact and hand-washing to recover amount of chlorpyrifos transferred was 1 hour (Fenske and Lu 1994).
[c]Estimated reported pressure of 6,900 pascals (Pa).

Legend:
ng/cm² = nanograms per square centimeter

Based on the foregoing discussion, most of the available FT_{ss} data presented in table 9-6 would tend to overestimate FT_{ss} for an office worker scenario. For evaluating office exposures, data from Brouwer et al. and Zainudin and Semple may be more appropriate because they did not focus on exposures to young children. The values also represent exposures from low to high surface loadings ranging from 6 to 1,830 μg/cm^2 (latter estimated from the data of Zainudin and Semple). Surface loading was previously identified as a factor that impacts transfer of contaminants from the surface to the skin. Although Zainudin and Semple did not report the pressure applied to the surface, it is reasonable to assume Zainudin and Semple asked subjects to use "normal" pressure because Zainudin and Semple focused on exposures in the work environment. It would have been helpful, however, if Zainudin and Semple had separated results for contact with smooth surfaces and tools such as pliers or screwdrivers.

Data from Brouwer et al. and Zainudin and Semple are somewhat comparable, with transfer efficiencies ranging from 0.14 to 2.1 percent (mean values from each study) for single contacts ranging from 5 to 10 seconds. However, office activities rarely consist of a single contact. While some contact events may be continuous (for example, talking on phone), others, such as typing, are more difficult to characterize. Results from Brouwer et al. and Rodes et al. show the amount transferred from the surface to the hands generally increases with consecutive contacts. At a surface load of 6 μg/cm^2, Brouwer and colleagues (1999) observed Tinopal® adherence to hands increased from 0.11 at the first contact to 0.38 μg/cm^2 at the sixth contact. The three-fold increase in adherence is comparable to that observed for the higher surface load, which went from 0.27 to 0.80 μg/cm^2. Calculating the fraction transferred using the Brouwer et al. assumption—that the transfer surface area is similar to the exposed hand area—estimated FT_{ss} would be 6.3 percent and 0.5 percent at surface loadings of 6 μg/cm^2 and 177 μg/cm^2, respectively. Brouwer et al. also measured the skin loading for 12 consecutive contacts at the higher surface load of 177 μg/cm^2 and reported an adherence of 1.07 μg/cm^2, which translates to a transfer factor of roughly 0.6 percent.

In Rodes et al. (2001), the researchers observed a gradually decreasing transfer of particles with each successive index fingertip press to the surface. Noting that particles were periodically lost and picked up again during successive contacts, the authors estimated an additional 40 presses increased the skin loading from the first press by only 30 percent. The researchers further estimated at least 100 presses were required to reach equilibrium where the amount picked up was the same as the amount lost from the hands. Using this assumption and results from their study, Rodes et al. (2001) extrapolated a transfer factor of about 0.15 to 0.20 for 100 consecutive presses.

Since office activity-specific FT_{ss} values are not available, a value of 6.3 percent (0.063) is recommended for estimating the amount transferred to the skin from contact with contaminated surfaces during a normal office activity. This value is based on results reported by Brouwer et al. for six repeated contacts at a low surface loading of 6 $\mu g/cm^2$. The estimate from Rodes et al. of 0.15 to 0.20 for 100 consecutive presses was not used to represent transfer for office activities because the range was extrapolated, not measured. In addition, the repetitive contacts experimental run from Rodes et al. was based on single fingertip presses to the surface, which probably overestimates the amount that would be expected to transfer from normal office activities.

9.2.1.3.2 Uncertainties and limitations

Risk assessors should be aware of the following uncertainties and limitations when applying the default FT_{ss}.

• If the default FT_{ss} is changed, the risk assessor should also consider whether the event frequency (paragraph 10.2.4) needs to be adjusted because the two parameters are directly related.

• Due to limited data, the default FT_{ss} recommended for any day-to-day office activity was estimated by using measurements collected from repetitive hand presses. Without actual office activity-specific FT_{ss} values to compare with, it is unknown where a transfer factor of 6.3 percent lies within the expected FT_{ss} range for normal office activities. However, based on results from Rodes et al. and Brouwer et al., the default FT_{ss} probably does not underestimate the amount transferred from normal office activities. First, FT_{ss} data are based on careful hand presses, which likely overestimate the amount of substance transferred to the skin from casual surface contacts (see next bullet). Second, Rodes et al. noted the skin surface is not a limitless reservoir. Their results showed an additional 40 surface contacts only increased the skin loading from the first contact by 30 percent.

• Experimental conditions often do not reflect actual exposures because subjects apply careful presses to the surface, and care is taken to ensure no transferred mass is lost from the hands prior to contaminant recovery from the hands. Under realistic exposure conditions, mass is continually picked up and lost from the skin. This may occur when the skin contacts a clean surface after contacting a contaminated surface (Brouwer et al. 1999), because of unintentional rubbing off of contaminant from the skin, or possibly as a result of removal by sweating (Fenske and Lu 1994). In addition, in an office environment, surface contacts do not consist of careful hand presses but casual contacts. Therefore, experimental FT_{ss} values may overestimate actual transfer, especially

for estimating long-term exposures because current methods assume whatever amount of mass is transferred to the skin is available for absorption.

• Current experimental designs use hand presses to estimate transfer of contaminants from the surface to the skin. Although the amount transferred corresponds to the actual skin surface area in contact with the contaminated surface, it is unknown whether creases, such as those on the palm, have an effect on transferability when compared to smooth body parts such as the forearm. For example, Rodes et al. (2001) found smudging increased the mass of dust transferred because particles are pushed into creases of the palm. Current FT_{ss} values assume transfer is the same for all body parts because no other data are available.

• Experimental values assume 100 percent of the contaminant transferred was recovered from the hands. When hands were washed immediately after contact with chlorpyrifos, 46 percent and 35 percent remained on the hands when ethanol and isopropanol/water were used as the hand-wash solvents, respectively (Fenske and Lu 1994). Therefore, studies that did not account for hand-wash removal efficiency or extraction efficiency potentially underestimate reported FT_{ss} values. This uncertainty does not apply to studies that use florescent tracing particles to estimate particle transfer. However, precision of the video imaging system used to estimate exposure could impact results (Brouwer et al. 1999).

• The default FT_{ss} was selected using office worker exposure assumptions and should not be applied to other exposure scenarios without considering additional factors for those scenarios. For example, children are more likely to contact surfaces with wet hands than adults, and experimental data show moisture can increase the amount transferred from the surface to the skin.

• Although it may be appropriate to separate FT_{ss} by residue and chemical type, there is insufficient data to provide substance-specific FT_{ss} values at this time. Future efforts should consider whether FT_{ss} values could be grouped based on a substance's physicochemical characteristics (for example, octanol-water partition coefficient).

9.2.1.4 Contaminant Surface Loading

Paragraph 8.2 discusses adjusting wipe sampling results to account for collection efficiency. Recommended fractions for metals and organics are 0.75 and 0.50, respectively.

9.2.2 Incidental Ingestion of Surface Contaminants

Incidental ingestion of surface contaminants is an indirect exposure pathway where substances on the surface are transferred from "mouthing behavior" or from ingestion of hand-held food items. The term "mouthing behavior" has typically been used to describe young children's hand-to-mouth contacts because this group of receptors has a high hand-to-mouth contact frequency (see USEPA 2005a). It describes both hand-to-mouth and object-to-mouth contacts, and may include "licking…insertion of fingers, hands, or objects in mouth" (USEPA 2005a). Although adults do not typically exhibit such behaviors, adults do have their own types of mouthing behavior, such as fingernail biting, chewing the ends of pens, or smoking a cigarette.

Transfer of contaminant from the surface to the mouth may be described as a two-step transfer process. First, the contaminant is transferred to the hands from direct contact with the surface. After this contact, contaminants on the hands may be transferred to the mouth via two ways—

• Hands touching the mouth or area around the mouth (for example, fingertip biting, licking the mouth area).

• Hands transferring the contaminant to hand-held food that is subsequently ingested (for example, a sandwich) or to other objects that are placed in the mouth (for example, a cigarette).

The potential ingested dose for the first scenario is estimated using equation 9-2. The first part of the equation is the same as equation 9-1 except the skin contact area is limited to the hands.

Equation 9-2

$$PD_{ing(ftp)} = (SA \cdot Fd \cdot FT_{SS} \cdot C_s) \cdot (F_f \cdot FT_{SM})$$

Where:

$PD_{ing(ftp)}$ = potential ingested dose per event (µg)
SA = exposed skin surface area per event (cm^2)
Fd = fraction of exposed skin surface area that actually contacts the contaminated surface (unitless)
FT_{SS} = fraction transferred from surface to the skin (unitless)
C_s = contaminant surface loading ($\mu g/cm^2$)
F_f = fraction of exposed skin area that contacts the mouth (unitless)
FT_{SM} = fraction of substance transferred from skin to mouth (unitless)

For contaminants transferred from the hands to items that are placed in the mouth or ingested (for example, a cigarette, food), the potential ingested dose requires an additional transfer factor. Equation 9-3 assumes the object has not been contaminated.

Equation 9-3

$$PD_{ing(hhi)} = (SA \cdot Fd \cdot FT_{SS} \cdot C_s) \cdot (F_{hhi} \cdot FT_{HI}) \cdot (F_m \cdot FT_{IM})$$

Where:

$PD_{ing(hhi)}$ = potential ingested dose from contact with hand-held item (µg)
SA = exposed skin surface area per event (cm^2)
Fd = fraction of exposed skin surface area that actually contacts the contaminated surface (unitless)
FT_{SS} = fraction transferred from surface to the skin (unitless)
C_s = contaminant surface loading (µg/cm^2)
F_{hhi} = fraction of hand area that touches the hand-held item (unitless)
FT_{HI} = fraction of substance transferred from hands to item (unitless)
F_m = fraction of hand-held item that touches the mouth (unitless)
FT_{IM} = fraction of substance transferred from hand-held item to mouth (unitless)

Another way in which surface contaminants may be incidentally ingested is from contact with an object that has been sitting on the surface (for example, a pen or pencil). Since there is already very little contaminant transfer data available, this scenario was excluded from further consideration at this time.

9.2.2.1 Skin Surface Area—Incidental Ingestion

The first step to estimating the potential ingested dose is to determine the amount of contaminant transferred from the surface to the skin. Unlike the total surface area used to estimate dermal absorption, the total contaminant mass that could be transferred from the skin to the mouth is limited only to the hands. Since office workers do not normally roll their hands around the work surface, the surface area is limited to the palmar side of the hands.

For this TG, exposures from incidental ingestion of surface contaminants were assumed to come from fingertip or fingernail biting (paragraph 9.2.2.5), ingestion of hand-held food items (paragraph 9.2.2.7), or cigarette smoking (paragraph 9.2.2.7). For the first two scenarios, the surface area of both hands (326 cm^2), as presented in paragraph 9.2.1.1, is recommended because both hands are equally likely to contact the mouth or touch the food item. However, transfer of

contaminants to the cigarette is assumed to come primarily from one hand (163 cm^2). Refer to paragraph 9.2.1.1 for uncertainties and limitations associated with the assumptions used to estimate the surface area.

9.2.2.2 Fraction of Skin Surface Area that Contacts the Surface (Fd)

As discussed in paragraph 9.2.1.2, Fd is used to modify the exposed skin area that actually contacts the surface. For this TG, the recommended Fd value is 0.30, which is 30 percent of the palmar surface area. Uncertainties and limitations for that recommendation are outlined in paragraph 9.2.1.2.

9.2.2.3 Fraction of Substance Transferred from the Surface to the Skin (FT_{ss})

Paragraph 9.2.1.3 provides a detailed discussion of the factors that affect the parameter, FT_{ss}. The recommended FT_{ss} value for this TG is 0.063 (6.3 percent), which is based on data from Brouwer et al. (1999). Uncertainties and limitations for that recommendation are outlined in paragraph 9.2.1.3.

9.2.2.4 Contaminant Surface Loading

Paragraph 8.2 discusses adjusting wipe sampling results to account for collection efficiency. Recommended fractions for metals and organics are 0.75 and 0.50, respectively.

9.2.2.5 Fraction of Exposed Skin Area that Contacts the Mouth (F_f)

9.2.2.5.1 Transfer factors

The parameter F_f in equation 9-2 modifies the portion of the exposed skin area that actually contacts the contaminated surface (that is, SA x Fd), and represents a fraction of this area that contacts the mouth during adult mouthing behaviors. To estimate this fraction, this TG uses nail biting or placing the fingertips in the mouth to represent common adult mouthing behaviors. The portion of the fingers placed in the mouth was assumed to be one-half of the last finger joint (that is, joint at the distal end of the finger). All fingers, including the thumb, were assumed to have an equal likelihood of being placed in the mouth.

Fingertip measurements that could be used to estimate F_f are limited. Although the USEPA Exposure Factors Handbook (1989a) provides skin surface area data for different parts of the body, no fingertip data is available from which fractions could be estimated. There is also little information available in the open literature. One study used a contact area of 30 cm^2 to estimate

intake from hand-to-mouth contaminant transfer (Michaud et al. 1994). However, the authors did not state how this value was derived other than that it represented the approximate surface area of the fingertips. In another study, Long and Finlay (1991) measured the fingertip lengths of 30 subjects to estimate a fingertip unit (FTU), a measurement used for the application of topical medicine. Since measurements were reported as lengths and not areas, the data could not be used to estimate F_f without some assumptions. An important observation noted by Long and Finlay was that although there was some variation between male and female FTUs (2.6 cm vs. 2.4 cm), FTU measurements were fairly consistent among subjects of the same sex.

Since no direct measurements of the fingertip area with respect to the hand area are available, F_f representing a fraction of the fingers was estimated using professional judgment. The following assumptions were used to estimate the fingertip fraction that contacts the mouth:

• Total finger area is one-half the hand area (0.5).

• The joint at the distal end of the finger is one-third of each finger (0.33). To simplify calculations, the same assumption was applied to the thumb.

• One-half of the joint at the distal end of the finger contacts the mouth (0.5).
Combining these fractions results in an F_f value of 0.08 (8 percent).

9.2.2.5.2 Uncertainties and limitations

Risk assessors should consider the following uncertainties and limitations when applying the recommended F_f value for estimating office worker exposures from incidental ingestion of surface contaminants:

• The fraction of the hands that contacts the mouth was estimated by assuming exposure occurs from fingernail or fingertip biting. If site-specific conditions suggest this fraction is higher, the risk assessor may want to consider whether F_f needs to be modified. The risk assessor needs to first consider that the total mass incidentally ingested per day depends on the event frequency (paragraph 10.3.2). Therefore, even if F_f increases, if the event frequency is significantly less than the number of fingertip biting events per day, the average daily intake could still be comparatively less, and the recommendations provided in this TG could still be applied to provide conservative estimates.

• The recommended F_f was derived by assuming office workers would be exposed to substances on the fingertips of all fingers on both hands. Although there may be individual variability, because F_f represents only a small fraction of the amount of substance transferred

from the surface, adjusting F_f to account for such variability is not expected to significantly impact the overall exposure. Similarly, impact resulting from variability between male and female data is expected to be minimal.

9.2.2.6 Fraction of Substance Transferred from Skin to Mouth (FT_{sm})

9.2.2.6.1 Transfer factors

The parameter FT_{sm} is used to estimate the amount of substance transferred from the skin to the mouth, and is also referred to as the saliva extraction factor by the USEPA (COPC Committee of the WTC IAWG 2003). The USEPA's pesticide programs apply a default value of 50 percent to estimate pesticide transfer from the hands to the mouth. Experimental studies indicate this parameter is influenced by many of the same factors that affect substance transfer from the surface to the hands (Kissel et al. 1998; Rusin et al. 2002).

As with other transfer factors, data that can be used to estimate FT_{sm} are limited. Kissel et al. (1998) measured the transfer of soil particles (< 2 millimeters (mm)) from the hands to the mouth for three different activities: thumb sucking, finger mouthing ("mouthing three fingers above the first knuckle"), and palm licking ("three swipes with the tongue"). Although these behavioral patterns are not representative of typical adult behaviors, results are useful for comparison purposes. Assuming soil particles were evenly distributed on the skin surface, the fraction transferred, as shown by the results of Kissel et al. (see table 9-7), increased with increasing skin contact area. However, when compared to the data of Rusin et al. (2002), this trend does not seem to apply. In Rusin et al., volunteers were asked to place a fingertip to the lower lip, which resulted in a much lower skin contact area with the mouth than the activities used by Kissel and his colleagues. Yet the estimated transfer fractions of Rusin et al. were all higher than those of Kissel et al. The best explanation is possibly due to the smaller particle size used by Rusin et al. A direct comparison of the surface loadings cannot be made because Kissel et al. reported surface loading as a mass per surface area while Rusin et al. expressed loading in number of colony-forming units (CFUs).

In another study, Zainudin and Semple (2005) measured the amount of Tinopal® transferred not to the mouth, but to the area around the mouth ("peri-oral" area). Zainudin and Semple used both Tinopal® powder and a Tinopal® solution (1.5 millilitre of 2.5 percent weight in weight (w/w)) as the test substances and observed a lower transfer fraction for fine powders than for liquids. Zainudin and Semple noted that since Tinopal® is known to bind to proteins, the estimated transfer fractions could be underestimated. The observations of Zainudin and Semple suggest the transfer of oily substances (for example, pesticide residues) may be lower than the transfer of particles.

Table 9-7. Summary of Hand-to-Mouth Transfer Data

Study	Test Substance	Activity	Contact Time	No. of Subjects/ Measurements	Fraction Transferred (unitless)
Kissel et al. 1998	Natural loamy sand (< 2,000 µm)	Thumb-sucking	10 seconds	4 (n = 36)	0.10
		Mouthing three fingers			0.159
		Three swipes of the palm with tongue			0.219
Rusin et al. 2002	*M. luteus* (gram positive)[1]	Place one fingertip to middle of lower lip	10 seconds	20 (n = 20)	0.4099
	S. rubidea (gram negative)[2]				0.3390
	Phage PRD-1[3]				0.3397
Zainudin and Semple 2005	Tinopal® (powder)	Normal behavior[4]	5 to 10 seconds	Unknown	0.082
	Tinopal® (liquid)				0.02

Notes:
[1]Size ranges from 0.05 to 3.5 µm (Dennis Kunkel Microscopy, Inc. 2007).
[2] *Serratia* species range in size from 0.5-0.8 µm x 0.9 to 2.0 µm (Sutton 2004).
[3]PRD-1 has a diameter of about 0.062 µm (Van Cuyk et al. 2005).
[4]Author's example of a "normal" office behavior was hand movement that came most naturally to an individual when asked to touch his or her face.

For this TG, results reported by Rusin et al. were used to estimate FT_{sm} for office worker exposures. The data from Rusin et al. are fairly consistent for the three different test substances, and the hand-to-mouth activity used to estimate the transfer fraction is more representative of office worker exposures. Although the data from Zainudin and Semple would also be applicable to office workers, Zainudin and Semple indicated the transfer fraction could be underestimated because Tinopal® binds strongly to protein. Therefore, until more data is available to compare and assess the different factors that impact FT_{sm}, this TG recommends an FT_{sm} of 0.4, a value rounded down from Rusin's estimated transfer fraction using *M. luteus* as the test substance.

9.2.2.6.2 Uncertainties and limitations

Risk assessors should consider the following uncertainties and limitations when applying the recommended FT_{sm} value.

• Particle size affects the amount of substance transferred from the hands to the mouth. Although the sizes of the test substances used by Rusin et al. fall within the particle size distribution of indoor particles (see paragraph 9.2.3.3.), indoor particle distribution is not expected to be homogenous. Therefore, transfer fractions estimated from studies that focus on test substances of a similar size could potentially be overestimated.

• Transfer factors from Rusin et al. were based on pressing a fingertip to the lower lip. Although this is similar to the assumptions used to estimate incidental ingestion for this TG (that is, fingertip or fingernail biting), it could overestimate or underestimate the fraction transferred for other types of mouthing behavior. Note that this is a limitation of the assumptions and does not suggest that the data from Rusin et al. is without uncertainty.

• Data used to estimate FT_{sm} are based on measurable particles and may not be representative of film-type residues. Data presented by Zainudin and Semple suggests the transfer fraction for liquid contaminants is lower than for particles. It is unknown whether the same comparison can be made of oil-based substances (for example, pesticides).

9.2.2.7 Fraction of Exposed Skin Area that Contacts a Hand-Held Item (FT_{hhi})

9.2.2.7.1 Contact factors

The parameter FT_{hhi} is used in equation 9-3 to estimate the amount of substance transferred from the hands to an item that is ingested (for example, a sandwich) or placed in the mouth (for example, a cigarette). This parameter modifies the portion of the exposed skin area that actually contacts the contaminated surface (that is, SA x Fd), and represents the portion of this area that contacts the hand-held item. To simplify assumptions, this TG assumes the hand-held item has not been in direct contact with a contaminated surface.

To estimate FT_{hhi}, the TG considered two typical office activities where the hand-held item is placed in the mouth: eating a sandwich and smoking a cigarette. Since total mass incidentally ingested depends on the number of contact events per day, both scenarios are discussed in this section. However, SWSLs are only developed for the scenario that provides the lowest screening levels (see chapter 6).

9.2.2.7.1.1 Estimating the fraction of the hand area that contacts an ingested "item"

As it is not practical to estimate FT_{hhi} for a variety of food items (for example, pretzels, potato chips, etc.), this TG limits this scenario to a food item that is commonly ingested in the office and where skin contact with the food item is the largest. Therefore, FT_{hhi} was determined by

estimating the fraction of hand area that contacts a sandwich or similar hand-held food (for example, a hamburger). This estimates how much of the "contaminated" hands actually touch the sandwich, not the amount that is transferred to the mouth, which is discussed in the next section.

Skin contact area for a sandwich-eating scenario was estimated by assuming the sandwich is held in both hands, with the thumb and all four fingers touching the sandwich. Using the same assumptions as in paragraph 9.2.2.5, total fingertip area was assumed to be about half of the hand area. It was further assumed that two-thirds of each finger was in contact with the sandwich. Combining these fractions results in an FT_{hhi} value of 0.33.

9.2.2.7.1.2 Estimating the fraction of hand area that contacts a cigarette

The fraction of hand area that contacts a cigarette is small in comparison to ingestion of food items, but this exposure scenario was included in this TG because the increased number of event frequencies could result in a higher average daily intake. To estimate F_{hhi} for this scenario, it was assumed the cigarette could come in contact with any part of the first two fingers and the thumb (palmar side). Using the same assumptions to estimate the fraction of exposed skin area that contacts the mouth (paragraph 9.2.2.5), if the area of the fingers represents half of the hand area, the fraction of hand surface area representing three fingers would be 0.33.

In summary, this TG recommends an FT_{hhi} of 0.33 for exposures from eating a hand-held food item, such as a sandwich, or from cigarette smoking. This fraction is currently the same for both scenarios because of the assumptions used. As more data become available, this fraction could be reevaluated to determine whether other values would be more appropriate.

9.2.2.7.2 Uncertainties and limitations

Risk assessors should consider the following uncertainties and limitations when applying the recommended FT_{hhi} value: Due to the lack of activity-specific data, professional judgment was exercised to estimate the fraction of hand surface area that comes in contact with the hand-held item. Since the assumptions were based on typical office worker behaviors, the estimated fraction may not be appropriate for other exposure populations such as young children.

9.2.2.8 Fraction of Substance Transferred from Hands to Item (FT_{hi})

9.2.2.8.1 Contact factors

The parameter FT_{hi} is used to estimate the amount of contaminants transferred from the hands to the hand-held item. The fraction transferred from the hands to a food item, such as a sandwich, and the fraction transferred to a cigarette are discussed separately below.

9.2.2.8.1.1 Estimating the fraction of substance transferred from hands to an ingested "item"

Since no data are available to estimate the amount of substance transferred from the hands to food items, an FT_{hi} of 1 (that is, 100 percent transfer) was assumed for evaluating exposures via this activity.

9.2.2.8.1.2 Estimating the fraction of substance transferred from the hand to a cigarette

Studies show that substances on the hands could be transferred to the cigarette during "normal handling" of the cigarette while smoking (Wolfe et al. 1975; USACHPPM 2003). Measuring the amount of parathion transferred from the hands of apple orchard workers, Wolfe et al. found an average parathion concentration of 34.2 µg/cigarette (n = 12) just from lighting the cigarette when the hands were dry. When the workers' hands were moist, the amount transferred increased to 80.0 µg/cigarette because the contaminant was able to penetrate the paper and enter the tobacco. Although the amount of parathion that could potentially be ingested might be small, Wolfe et al. noted the exposure could become significant for workers who smoke a pack of cigarettes (20 cigarettes) a day. Since Wolfe and his colleagues did not measure the amount of parathion on the workers' hands, FT_{hi} could not be estimated from Wolfe's study.

Researchers in another study looked at the transfer of Skin Exposure Reduction Paste Against Chemical Warfare Agents (SERPACWA) from the hands to cigarettes (USACHPPM 2003). The substance contains both an oil-based and a powder-based polymer, and is applied to the skin as a physical barrier against CWAs. Ten volunteers were asked to "mimic" smoking for 10 minutes after applying SERPACWA as directed and wiping their hands with paper towels. The authors measured the weight of each cigarette before and after the scripted activity, as well as the amount of SERPACWA on the hands after wiping with a paper towel (table 9-8). Similar to data reported by Wolfe et al., the researchers at USACHPPM found that hand-washing significantly reduced the amount of substance available for transfer to the cigarette.

Table 9-8. Estimated Mass of SERPACWA Transferred From Hand to Cigarette (USACHPPM 2003)

Description	Mean (grams) No. of Measurements	Range (grams)	Notes
SERPACWA remaining on both hands	5.18 (4)	4.208–6.434	Estimated by measuring the weight of the paper towel before and after hand-wiping
Amount of SERPACWA transferred, unwashed hands	0.058 (10)	0.043–0.082	Estimated by subtracting the weight of the cigarette before the simulated smoking (10 minutes) and the weight of the cigarette after smoking
Amount of SERPACWA transferred, hands washed with soap and water	0.003 (10)	0.001–0.005	Same as above

The fraction of SERPACWA transferred from the hands to the cigarette can be estimated by dividing the reported mass of SERPACWA on the cigarette by the mass of SERPACWA remaining on the hands. It is unknown whether the volunteers in the USACHPPM study handled the cigarettes with both hands. However, since subjects were asked to handle cigarettes "in a way characteristic of smokers," it seems reasonable to assume that most of the substance transferred would have come from each subject's dominant hand. Therefore, the mass remaining on the hands was divided by two to estimate the amount of SERPACWA transferred to the cigarette.

Using the average mass, the estimated fraction transferred from one hand to the cigarette is 0.02 (2 percent) or a range from 0.013 to 0.04 (1.3 percent to 4 percent) for unwashed hands. For the purposes of this TG, an FT_{hi} of 0.02 is used to estimate the amount of substance transferred to the cigarette during smoking.

Table 9-9 summarizes FT_{hi} values to be used to estimate the amount of substance transferred from the hands to ingested items, such as a sandwich, and from the hands to a cigarette.

Table 9-9. Recommended FT_{hi} Values

"Items" in Consideration	Recommended Value
Food items such as a sandwich or a hamburger	1
Cigarettes	0.02

9.2.2.8.2 Uncertainties and limitations

Risk assessors should understand the uncertainties and limitations of the recommended FT_{hi} values in this TG.

• Due to the lack of information, this TG recommends an FT_{hi} of 100 percent for food items, which is likely to overestimate exposure for this scenario. The estimated FT_{hi} for a cigarette was not used for food items because common sense suggests the amount of substance transferred from the hands to food items, such as sandwiches, might be higher than the amount transferred to cigarettes. One factor to consider is the amount of pressure applied while holding the hand-held item. Another is the "greasiness" of the food because the grease may increase the amount of substance transferred.

• Since SERPACWA is intended to serve as a skin barrier against CWA, it was probably formulated so that it would not be easily rubbed off the skin. This could result in an underestimation of the transfer fraction for substances that are easily removed from the skin.

• Personal habits such as hand-washing may not completely eliminate certain substances (for example, lipophilic substances) transferred to the hands, but could significantly reduce exposure. For example, the USACHPPM study reported a small but measurable amount of SERPACWA transferred to cigarettes even after volunteers washed their hands with soap and water. However, the mass transferred is over three orders of magnitude less than the amount transferred when hands were not washed. Still, Wolfe et al. observed that the workers in their study did not normally wash their hands before eating or smoking; therefore, unless site-specific information indicates otherwise, for the purpose of selecting FT_{hi} values, risk assessors should assume workers do not have the habit of washing their hands.

9.2.2.9 Fraction of Hand-Held Item that Contacts the Mouth (F_m)

9.2.2.9.1 Contact factors

The fraction of the hand-held item that contacts the mouth (F_m) accounts for the fact that only a portion of the contaminated "item" may come in contact with the mouth. The fraction transferred from a food item, such as a sandwich, and the fraction transferred from a cigarette to the mouth are discussed separately below.

9.2.2.9.1.1 Estimating the fraction of ingested "item" that contacts the mouth

For this TG, the food item (for example, a sandwich) was assumed to be completely ingested so no fractioning of the sandwich surface area that contacts the mouth was required. This results in a 100 percent transfer of substance from the food item to the mouth, or an F_m value of 1.

9.2.2.9.1.2 Estimating the fraction of cigarette that contacts the mouth

Cigarettes, unlike food, are not intentionally ingested; therefore, F_m was estimated by assuming only the filter part of the cigarette was placed in the mouth. To estimate this fraction, dimensions of a Quest 3® cigarette were measured to estimate surface areas. Since the lengths of regular-sized cigarettes are fairly standard, only one measurement was taken. Figure 9-2 shows the measured dimensions and calculated surface areas needed to estimate the fraction of cigarette that is the filter. (Quest 3® is a registered trademark of Vector Tobacco Inc., Research Triangle Park, North Carolina.)

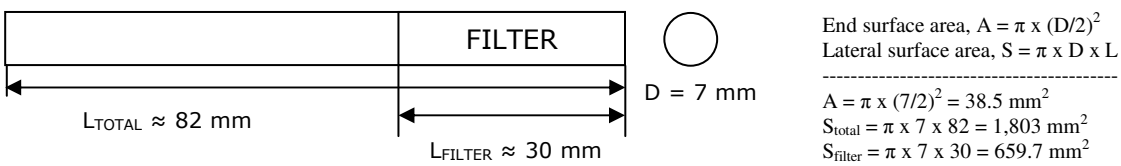

Figure 9-2. Dimensions of a Regular-Length Cigarette

Based on the measurements shown in the figure, the estimated fraction of the cigarette that could be placed in the mouth is 37 percent (0.37). A slightly lower filter-to-cigarette surface area was found for "extra long" cigarettes (35.5 percent), but the overall fraction is similar. Table 9-10 summarizes F_m values to be used to estimate the fraction of hand-held item that comes in contact with the mouth.

Table 9-10. Recommended F_m Values

"Items" in Consideration	Recommended Value
Food items such as a sandwich or a hamburger	1
Cigarettes	0.37

9.2.2.9.2 Uncertainties and limitations

Risk assessors should consider the following uncertainties and limitations to determine whether the recommended F_m values are appropriate for their exposure scenarios.

• The fraction of hand-held item that contacts the mouth is not expected to significantly impact final health risk estimates because it represents a small fraction of the amount of substance transferred from the surface. Therefore, if the risk assessor needs to refine health risk estimates, the risk assessor is advised to evaluate other parameters first before determining whether to modify F_m to reflect site-specific conditions. Estimating F_m will most likely require some assumptions and professional judgment because of the difficulty associated with measuring this parameter. For food items, it is reasonable to assume an F_m value of 100 percent because food items are ingested.

• The fraction of cigarette that contacts the mouth was estimated by assuming the entire filter area could be placed in the mouth during smoking. This probably overestimates the F_m value of the cigarette but is not expected to significantly affect the overall estimated intake because F_m is one of several fractions that modify the original mass transferred from the surface.

9.2.2.10 Fraction of Substance Transferred from a Hand-Held Item to the Mouth (FT_{im})

9.2.2.10.1 Transfer factors

The parameter FT_{im} estimates the amount of substance that is transferred when the item is in contact with the mouth. As with the fraction of substance transferred from the skin to the mouth (FT_{sm}), FT_{im} is expected to be affected by many of the same factors discussed in paragraph 9.2.1.3 (fraction transferred from the contaminated surface to the skin). Although it is reasonable to assume a 100 percent transfer for food, there is currently limited data available to estimate the fraction transferred from objects that are placed in the mouth. Therefore, until more data become available, this TG recommends an FT_{im} of 1 (100 percent) for all hand-held items.

9.2.2.10.2 Uncertainties and limitations

The following uncertainties and limitations apply to the FT_{im} recommended for this TG: An FT_{im} of 1 is recommended at this time because of the lack of data. While this is a reasonable assumption for estimating food items because they are usually fully ingested, this fraction most likely overestimates the amount of substance transferred from items such as cigarettes. As with the parameter F_m, estimating FT_{im} will most likely require some assumptions and professional judgment because of the difficulty associated with measuring this parameter.

9.2.3 Inhalation of Resuspended Surface Contaminants

Human activities stir up surface contaminants, making them airborne and available for inhalation. However, inhalation of surface contaminants is not expected to contribute significantly to the overall health risk estimates. One study involving chlorpyrifos concluded exposure via inhalation was negligible while direct skin contact and non-dietary exposure from mouthing behavior of contaminated objects accounted for 39 percent and 61 percent, respectively, of a child's total dose (Gurunathan et al. 1998). Nishioka et al. (2001), estimating potential health risks to a 1- to 2-year-old, similarly concluded exposure from inhalation contributed from less than 1 percent to 2 percent of the child's total dose.

Although studies have demonstrated inhalation of indoor airborne contaminants only accounts for a fraction of the overall exposure, if inhalation is the primary route of exposure or if inhalation toxicity is a concern, inhalation of airborne contaminants could be a significant exposure pathway. Therefore, this TG provides a method for estimating resuspended air concentrations for contaminants that are known or reasonably believed to pose significant health risks when inhaled. Users should use professional judgment to determine whether inclusion of this pathway is appropriate. For example, if actual air sampling results are available, there is no need to estimate the resuspended air concentration using models. Decisions not to include this exposure pathway should be thoroughly discussed.

Estimating resuspended particulate concentration is difficult because the amount resuspended is influenced by many factors, which are summarized below—

• Indoor environment characteristics. This includes ventilation rates, room volume, and relative humidity. Buildings with superior filtration systems effectively remove particles from a room, resulting in less mass available for resuspension. Occupant activity/habit also affects the mass and size distribution of particles available for resuspension. For example, cooking and smoking are important sources of indoor particles, especially those less than 2.5 µm (Long et al. 2000; Abt et al. 2000a). However, these common residential sources are normally absent from large commercial buildings (Fisk et al. 2000). The type of furnishings also affects particle mass. Carpets collect more dust than linoleum floors, but dust on smooth surfaces is more easily resuspended than dust on carpets (Thatcher and Layton 1995; Ko and Burge 2004).

• Particle characteristics. Resuspension is also affected by particle size, shape, electrostatic charge, and density. Some studies suggest particle size is the single most important factor affecting the ease of particle removal from a surface (Rodes et al. 2001). This may be explained in part by the adhesion forces of particles which increase with decreasing particle size (Abu-Eid et al. 2002). Smaller particles are also more likely to agglomerate, making them heavier and

more difficult to resuspend. However, once resuspended, fine particles (1 to 5 μm in diameter) will remain airborne longer than larger particles (Thatcher and Layton 1995). Chemical composition of the dust may also affect particle resuspension. A group of Danish researchers reported higher organic content in resuspended dust than settled dust (Mølhave et al. 2000). The authors reasoned the higher density of inorganic particles make them heavier and less easy to resuspend than organic particles.

• Mechanism of resuspension. Activity intensity impacts how much particle is resuspended from a surface. For example, vacuuming and cleaning may generate more airborne particles than walking in and out of a room (Thatcher and Layton 1995). It has been suggested elsewhere that the degree of particle resuspension is proportional to the number of people present (Ness 1994).

• Surface characteristics. The ease of particle resuspension is also influenced by surface type and coating. Ferro et al. (2004) found that dancing on a rug generated seven times more $PM_{2.5}$ (particulate matter (PM) less than 2.5 μm in size) than dancing on a wood floor in the same location; nine times more PM_5 were generated for those same conditions. However, particles smaller than 1 micron (1 μm) may not be readily dislodgeable from carpets (Rodes et al. 2001). Ko and Burge (2004) also demonstrated surface treatments such as silicon-containing furniture polish may cause dust to bind more tightly to surfaces, resulting in less airborne particles. In addition, relative humidity enhances a surface's adhesive properties, making it more likely for particles to stick to the surface (Rodes et al. 2001).

• Decontamination activities. Remedial actions affect the availability of particles for resuspension (Abu-Eid et al. 2002; Biwer et al. 2002). Particles deposited on surfaces that have not been cleaned are "loosely bound" and easily resuspended. Remediation removes "loose" particles and remaining particles are more tightly bound to the surface (Biwer et al. 2002; Yu et al. 2003).

Most models use a resuspension factor (K) or a resuspension rate (R) to estimate the concentration of resuspended particles in the air. A resuspension factor is the ratio between the airborne concentration (microgram per cubic meter ($\mu g/m^3$)) and the amount deposited on a surface (microgram per square meter ($\mu g/m^2$)) (Ness 1994; Loosmore 2003). Resuspension rate is the resuspension flux ($\mu g/m^2$-hr) from the surface divided by the initial surface loading ($\mu g/m^2$) (Loosmore 2003). More simply, R represents the rate at which surface contaminants are resuspended into the air.

The most basic way to estimate the airborne concentration is to multiply the measured surface depositions by empirical or estimated values of K from the literature (see USACHPPM 1999a). This approach had traditionally been used by the radiation community to correlate airborne concentrations to surface concentrations (Caplan 1993). Although other models are not without

uncertainty or variability, using this basic relationship to estimate the airborne concentration restricts the ability to adjust factors that affect particle resuspension. Other indoor air models incorporate a room's air exchange rate and volume to estimate the airborne concentration. These models also permit the inclusion of various terms to account for loss of resuspended particulates from the air. However, they also inevitably rely on measured or reported R or K values to estimate airborne concentrations.

Ignoring other sources of airborne contaminants and losses such as decay and removal by filtration, particle resuspension may be defined as follows (Biwer et al. 2002; Yu et al. 2003; Freihaut et al. 2005):

Equation 9-4

$$\frac{dC_{air}}{dt} = C_s \cdot \frac{A_s}{V} \cdot R - \left(C_{air} \cdot \lambda_{dep} - C_{air} \cdot \lambda_a\right)$$

Where:

dC_{air}/dt = resuspended air concentration at time (concentration/time)
C_s = contaminant surface deposition or loading (mass/area surface)
A_s = source area
V = room volume
R = resuspension rate (1/time)
C_{air} = resuspended air concentration (mass/volume air)
λ_{dep} = deposition loss rate (1/time)
λ_a = air exchange rate (number of air exchanges/time)

Equation 9-4 states the airborne concentration at any given time is the resuspended air concentration less loss from particle deposition and removal by the ventilation system in the room. For the purposes of this TG, it would not be practical to calculate airborne concentrations using a dynamic model although the user is not precluded from doing so. Instead, airborne concentrations are estimated by assuming steady-state, well-mixed conditions (that is, $dC_{air}/dt = 0$), which gives a constant concentration at any given time. In reality, this is untrue as the airborne concentration will fluctuate with time, with the highest concentration observed immediately following a disturbance, and, if no further disturbance occurs, the particles will eventually settle back to the surface (Thatcher and Layton 1995). Therefore, risk assessors should take into account the type of disturbance activity used to estimate the resuspension rate. This is further discussed in paragraph 9.2.3.2. Equation 9-4 reduces to the following when steady-state conditions are assumed:

Equation 9-5

$$C_{air} = \frac{C_s \cdot 10^4 \cdot A_s \cdot R}{V \cdot \lambda_{dep} + V \cdot \lambda_a}$$

Where:

C_{air} = resuspended air concentration (μg/m^3)
C_s = contaminant surface deposition or loading (μg/cm^2)
10^{-4} = units conversion from cm^2 to m^2
A_s = source area (m^2)
V = room volume (m^3)
R = resuspension rate (1/hr)
λ_{dep} = deposition loss rate (1/hr)
λ_a = air exchange rate (number of air exchanges/hr)

Equation 9-5, without the deposition loss term, has been used by the National Research Council to estimate the resuspension of anthrax spores from indoor surfaces (National Research Council 2005). Use of this equation assumes the contaminant is resuspendable, existing either in a "free" state or partitioned to a particle such as dust. In addition, particle resuspension (estimated using R) and deposition (estimated using λ_{dep}) depend on particle size; therefore, equation 9-5 should be applied separately for each particle size range of interest. For estimating potential health hazards from inhalation of chemicals, particle size range should consider only those chemicals that are able to penetrate and deposit in the pulmonary regions of the lungs where they can be absorbed (Abu-Eid et al. 2002; Biwer et al. 2002). If R is available only for the total mass, the risk assessor could consider adjusting the air concentration by the respirable fraction (f_{resp} in equation 9-6). More on the respirable fraction is discussed below.

Equation 9-6

$$C_{air} = \frac{f_{resp} \cdot C_s \cdot 10^4 \cdot A_s \cdot R}{V \cdot \lambda_{dep} + V \cdot \lambda_a}$$

For screening evaluations, the U.S. Nuclear Regulatory Commission assumes only 10 percent of surface contamination is removable, which is distinguishable from the respirable fraction, for sites that have been decommissioned (Abu-Eid et al. 2002). A similar adjustment for decontaminated surfaces is not recommended for this TG because of the uncertainties associated with current surface wipe sampling methods. For now, it is assumed contaminants dislodgeable

by wipe sampling are equally capable of being resuspended from the surface, keeping in mind resuspension only involves settled particles and not residues such as films left behind after some pesticide application.

9.2.3.1 Contaminant Surface Loading

Paragraph 8.2 discusses adjusting wipe sampling results to account for collection efficiency. Recommended fractions for metals and organics are 0.75 and 0.50, respectively. As discussed above, inclusion of the inhalation pathway assumes the surface substances can be resuspendable.

9.2.3.2 Resuspension Rate (R)

9.2.3.2.1 Resuspension factors

The resuspension rate is the rate at which settled particles are resuspended into the air. This parameter cannot be measured directly but is normally estimated from experimental measurements of airborne and surface concentrations over time (Loosmore 2003; Thatcher and Layton 1995). For evaluating inhalation exposures, air samplers should ideally be placed at a height representative of the breathing zone.

The resuspension rate (R) may also be estimated from the resuspension factor (K) by assuming steady-state conditions (Biwer et al. 2002; Yu et al. 2003):

Equation 9-7

$$R = K \cdot \left(v_{dep} + \lambda_a \cdot H \right)$$

The parameters on the right side of equation 9-7 correspond to values from experimental conditions; H is the room height and V_{dep} is the deposition velocity, which is another form of expressing the deposition loss rate, λ_{dep}. Since K is simply a ratio of the air-to-surface concentration, it is the parameter that is more often reported in the literature than R. Thus, equation 9-7 is useful when only values of K are available.

Due to the many factors that affect particle resuspension from indoor surfaces, literature values of R or K are highly variable. These factors have already been discussed (see paragraph 9.2.3) and will not be repeated here. The user should keep those factors in mind and select values of R that are representative of the exposure scenario being assessed. For example, for office worker exposures, preference is for values of R derived from commercial buildings with similar characteristics (for example, size of building, ventilation system) and activity patterns. In

addition, values of R will be affected by remedial activities which remove easily suspendable particles and leave behind particles that are more tightly bound to the surface (Biwer et al. 2002; Yu et al. 2003; Abu-Eid et al. 2002).

At this time, choosing the most representative R values is hampered by the lack of data, especially for nonindustrial environments. Three major literature reviews of R and K values have been identified. The first was conducted by the U.S. Nuclear Regulatory Commission, formerly the Atomic Energy Commission, for the purpose of establishing "decision levels" for radioactive materials on indoor surfaces (Healy 1971). Healy reviewed experimental results from three groups of researchers and noted the data were not applicable to homes as measurements were taken from "typical industrial areas." Based on reasonable assumptions and what was known about indoor particle resuspension at the time, Healy proposed R values for four different activity levels in the home. These values are tabulated in table 9-11.

The second review by Sansone (1987) included those studies examined by Healy. Sansone summarized values of K obtained or calculated from 25 different studies which ranged from 10^{-9} to 10^{-2} per meter. The wide range observed is not surprising considering the different experimental conditions which varied from vigorous floor sweeping to no disturbance at all, no ventilation to air changes up to 20 per hour, or concrete to steel floors. Although these studies could be useful for comparison purposes, they were not individually evaluated for applicability at this time because they were measured mostly from industrial conditions and focused on resuspension of radioactive material or microorganisms from the floor. In addition, since Sansone reported values of K and not R, significant resources would be required to locate each article and to determine whether sufficient information is reported to estimate equivalent R values. Much of this review has already been conducted by researchers at the Argonne National Laboratory (ANL), whose work is discussed next.

The ANL conducted a thorough review of K and R values as part of an effort to develop a computer model (RESRAD-BUILD) for estimating radiation exposures to persons inside a contaminated building (Biwer et al. 2002; Yu et al. 2003). The RESRAD-BUILD user manual describes occupants as persons who "live or work" in the building while a prior report prepared for the U.S. Nuclear Regulatory Commission refers to a "light industrial" use. Since RESRAD-BUILD uses a resuspension rate, the developers of the model reviewed numerous studies but relied only on the ones from which the resuspension rate could be calculated (equation 9-7). Deposition velocities were assumed because none of the studies measured this parameter (Biwer et al. 2002; Yu et al. 2003). Table 9-12 lists the resuspension rates calculated and considered for the RESRAD-BUILD model. After comparing calculated R values from eight different sources, which also included the three previously reviewed by Healy, the ANL researchers selected a

default value of 5×10^{-7} s^{-1} for evaluating nonindustrial exposures (Yu et al. 2003). The RESRAD-BUILD model also provides a default log-uniform distribution (2.5×10^{-11}, 1.2×10^{-5} s^{-1}) for conducting probabilistic assessments (Biwer et al. 2002; Yu et al. 2003). The low end of this distribution was selected from the lowest R value calculated from the eight studies, and intended to represent any type of activity in an occupational setting (Biwer et al. 2002; Yu et al. 2003). The RESRAD-BUILD developers noted recommended R values are currently independent of particle size because of insufficient data to select values that correspond only to the respirable fraction (Biwer et al. 2002; Yu et al. 2003).

Table 9-11. Summary of Selected Resuspension Rates

Source	Particle Information	R (hr^{-1})[a]	Indoor Characteristics	Activity	Comments
Healy 1971	None	5×10^{-3}	Residential	• Vigorous (cleaning; children at active play or running) • Active (normal traffic; children at normal play)	Values were not derived from actual experimental study but assumed after the author reviewed data from several sources.
		5×10^{-4}		• Moderate (reading, watching TV, occasional movement)	
		5×10^{-6}		• Quiet (unoccupied room, sleeping)	
Yu et al. 2003	None	1.8×10^{-4}	Occupants who live or work indoors (nonindustrial)	Those representative of occupational and residential occupants	Value was not derived from actual experimental study but selected after the authors reviewed data from several sources.
Thatcher and Layton 1995	0.3-0.5 µm	9.9×10^{-7}	• Two-story home, first floor area 150 m^2, second floor areas 80 m^2 • Air infiltration rate: 0.3/hr • Assumed 40% carpeted, 60% hard surfaces	Four residents performing "normal" activities	• Samples take 2 m above floor to simulate breathing zone of standing person. • Assumptions used to calculate R: ° Particle density: 1 gram per cubic centimeter (g/cm^3) ° Particle deposition loss rates assumed 0 for particles < 1 µm ° Only first story occupied ° Total house volume well mixed ° Total dust mass loading used for all sizes since floor dust sizes not differentiated. Thatcher and Layton noted this tends to yield "artificially low" R values.
	0.5-1 µm	4.4×10^{-7}			
	1-5 µm	1.8×10^{-5}			
	5-10 µm	8.3×10^{-5}			
	10-25 µm	3.8×10^{-4}			
	>25 µm	3.4×10^{-5}			

Table 9-11. Summary of Selected Resuspension Rates (continued)

Source	Size Bins (Average)	R (hr^{-1})[a]			Indoor Characteristics	Comments
		Quartz	Dust Mite	Spores		
Bahnfleth et al. 2007	0.3-0.39 µm (0.345)	2.74×10^{-4}	2.12×10^{-4}	1.64×10^{-3}	Linoleum surface	• Study conducted in experimental chamber (40x20x20 cm) (Gomes et al. 2007) • Floor disturbance produced by mechanical vibration and "air swirl" of 1.5 meters per second (m/s) horizontal air velocity to simulate walking • Dust loads of 0.5 g/m^2 and 2.5 g/m^2 on 9- by 9-cm floor samples. Since dust load did not significantly impact R, results from both dust loads were combined.
	0.4-0.49 µm (0.445)	1.90×10^{-4}	3.59×10^{-5}	1.21×10^{-4}		
	0.5-0.64 µm (0.57)	1.94×10^{-4}	3.10×10^{-5}	2.23×10^{-4}		
	0.65-0.79 µm (0.72)	1.77×10^{-4}	4.07×10^{-5}	2.13×10^{-4}		
	0.8-0.99 µm (0.895)	1.83×10^{-4}	2.15×10^{-5}	2.75×10^{-4}		
	1.0-1.59 µm (1.295)	7.62×10^{-5}	5.83×10^{-5}	3.66×10^{-4}		
	1.6-2.0 µm (1.8)	1.26×10^{-4}	2.11×10^{-5}	3.08×10^{-4}		
	>2.0 µm (2)	2.83×10^{-5}	8.40×10^{-5}	2.47×10^{-4}		
	0.3-0.39 µm (0.345)	5.57×10^{-4}	8.28×10^{-4}	5.00×10^{-2}	Exterior plastic grass carpet	
	0.4-0.49 µm (0.445)	4.44×10^{-4}	8.88×10^{-5}	3.34×10^{-3}		
	0.5-0.64 µm (0.57)	6.06×10^{-4}	2.74×10^{-4}	5.75×10^{-3}		
	0.65-0.79 µm (0.72)	2.99×10^{-4}	1.90×10^{-4}	7.08×10^{-3}		
	0.8-0.99 µm (0.895)	3.68×10^{-4}	1.45×10^{-4}	7.80×10^{-3}		
	1.0-1.59 µm (1.295)	5.02×10^{-4}	2.44×10^{-4}	1.06×10^{-3}		
	1.6-2.0 µm (1.8)	2.80×10^{-4}	2.36×10^{-4}	8.40×10^{-3}		
	>2.0 µm (2)	7.80×10^{-5}	1.67×10^{-4}	7.62×10^{-3}		

Note:
[a]Data from Yu et al. (2003) converted from s^{-1}; data from Bahnfleth et al. (2007) converted from min^{-1}.

Legend:
g/m^2 = grams per square meter

Thatcher and Layton (1995) conducted one of the few studies that looked at resuspension of settled particles by different size range. Since R is not a directly measurable parameter, the authors calculated R from actual measurements of particle air concentration and deposition loss rates. Deposition rates for particles less than 1 µm were assumed to be zero (0) because they were not measured for those particles. Table 9-12 summarizes other assumptions Thatcher and Layton used to estimate R for six particle size ranges. Data presented are based on four people performing normal activities, such as walking and sitting, which the authors described as "light" activities. Thatcher and Layton measured indoor air concentrations for 5 and 30 minutes of activity but did not state which results were used to estimate R. Since the authors observed no significant change in air concentration between the scenarios, it is presumed calculated Rs are applicable to either 5 or 30 minutes of normal activity.

The results of Thatcher and Layton show particles less than 1 µm have a much lower resuspension rate than particles larger than 5 µm. These results are in general agreement with Ferro et al. (2004) who evaluated the strength of particle resuspension from various human activities and observed most particles resuspended were larger than 5 µm. Only less than 1 percent (by volume) of the total suspended particles measured during the 5-hour experimental period were less than 1 µm in diameter (Ferro et al. 2004). Although the developers at ANL also reviewed Thatcher and Layton's results, they did not select the values outright for use in RESRAD-BUILD.

Thatcher and Layton also observed particle generation from other disturbances, but did not calculate R for those activities. They did, however, provide a relative comparison of the amount of particles generated between each activity by measuring the indoor air concentration after each disturbance and comparing it to the air concentration measured before that activity. Other activities observed were vigorous vacuuming and housecleaning, 2 minutes of continuous walking and sitting in the living area by one person, and walking in/out of the living room by one person. For particles less than 5 µm, the amount of particles generated from all disturbances was comparable except for cleaning, which had an "after/before activity" ratio twice that of other activities for particles in the 1- to 5-µm size range. Cleaning also dominated as the major particle generator for larger particles, with an "after/before activity" ratio of 11.4 for particles between 5 to 10 µm. By comparison, four persons performing normal activities for 30 minutes only generated roughly twice the amount of particles in the same size range.

The Pennsylvania State University Indoor Environment Center is developing a tool for estimating bioaerosol concentration indoors (Bahnfleth et al. 2007). The tool, which is still under development, includes resuspension rates measured by Gomes et al. (2007) for three particle types and eight size "bins." Particles larger than 2 µm are assumed to have the same characteristics as those measured for 2-µm particles. Table 9-12 summarizes values measured by

Gomes et al. and used by Bahnfleth et al. in their model. Data based on resuspension from exterior plastic carpet are also included even though this TG focuses on nonporous surfaces because experimental values of R are so few. Tabulated data show particle resuspension from "carpet" surface is higher than from linoleum surface for all size bins. However, Gomes et al. (2007) reported opposite results for a different set of experiments using quartz and roach dust. This suggests there may be some kind of threshold for the major factors that impact particle resuspension—when one threshold is met, impact from that factor levels off, and the effects of another factor become more significant.

Data presented in table 9-12 show values of R vary by orders of magnitude even for particles of the same size range. For example, Rs reported in Bahnfleth et al. range from 1.77 to 2.74 x 10^{-4} per hour for quartz particles less than 1 µm, in contrast to a range of 4.4 to 9.9 x 10^{-7} estimated by Thatcher and Layton. The main reason for the large discrepancy may be because Gomes et al. used a controlled environment to measure resuspension rates, while Thatcher and Layton estimated resuspension rates from inside an occupied home. The data from Gomes et al., although useful for understanding the significance and impact of various factors on resuspension, may be limited for simulating actual resuspension. Thatcher and Layton's results are also limited, although for different reasons—their data are based only on measurements from a single home. Therefore, until more data become available, a resuspension rate of 1.8 x 10^{-3} per hour (1.8 x 10^{-3} hr^{-1}) is recommended as an interim default for estimating the resuspended air concentration. This value is based on the deterministic resuspension rate recommended by ANL for estimating radiation dose to people who work or live in contaminated buildings. Although at the high end of other resuspension rates tabulated in table 9-12, the value recommended by ANL falls within the default probabilistic range used by the ANL researchers in RESRAD-BUILD. As discussed below, this value probably overestimates resuspension concentrations used to estimate long-term exposures for the office worker scenario.

9.2.3.2.2 Uncertainties and limitations

Due to the lack of indoor particle resuspension data, the interim default R provided in this TG contains a high level of uncertainty. Risk assessors should keep the following issues in mind when applying this default value. If additional information (ventilation rate, level of activity) about the indoor environment to be assessed is available, the user could consider whether some other value, such as those listed in table 9-11 or table 9-12, may be more appropriate. As a reminder, if a size-specific R is selected, the f_{resp} should be adjusted accordingly.

• Experimental designs typically focus on measuring resuspension of particles from the entire floor. Office workers spend most of their time sitting. Thus, the primary source of resuspended particles probably comes from office furniture such as desk or chair surface, which has a smaller

surface area available for particle collection. Even though office workers do move around or may be exposed to resuspended particles caused by other indoor activities (for example, renovation), those exposures are expected to be intermittent and/or short-lived. Therefore, experimental values of R probably overestimate the amount of settled particles resuspended from normal office worker activities.

• Resuspension activities used in experiments often involve those that cause a significant amount of particle resuspension. For example, Thatcher and Layton (described above) observed particle generation from 2 minutes of continuous walking and sitting and vigorous vacuuming and house cleaning. These movements are often unrealistic for estimating long-term exposures in an office environment.

• Settled particle concentration indoors is rarely ever homogenous. The many factors that contribute to this variation are those that affect particle source (for example, building material, cooking) and removal of these particles (for example, frequency of cleaning). A default resuspension rate could overestimate/underestimate the amount of particle resuspended for a room that is quite different from the conditions used to measure the default resuspension rate. Using default values from current experimental data is also likely to overestimate particle resuspension from remediated surfaces because particles remaining after remedial activities bind more tightly to the surface (Biwer et al. 2002).

• One group of researchers consistently found a higher organic carbon content, including CFU, in airborne particles than in settled particles (Mølhave et al. 2000). Mølhave et al. speculated that inorganic particles are heavier and thus not easily resuspended. Results from this study suggest experimental values of R could overestimate/underestimate the concentration of specific chemicals in airborne dust. At this time, it is unknown whether this factor is significant enough to warrant chemical-specific values of R.

Table 9-12. Indoor Resuspension Rates Calculated and Compiled by Argonne National Laboratory[a]

Resuspension Rate (1/s)		Resuspension Factor (1/m)	Air Exchange Rate (1/hr)	Room Height (m)	Conditions	Source
Minimum	Maximum					
7.7×10^{-7}	1.1×10^{-6}	1.2×10^{-4}	9.0	2.59	4 to 6 people walking; change room	Brunskill 1967
5.1×10^{-10}	5.1×10^{-7}	1.9×10^{-4}	0.0	2.44	Vigorous work, including sweeping	Fish et al. 1967
1.1×10^{-10}	1.1×10^{-7}	3.9×10^{-5}			Vigorous walking	
2.5×10^{-11}	2.5×10^{-8}	9.4×10^{-6}			Collecting contaminated samples	
1.9×10^{-9}	1.9×10^{-6}	7.1×10^{-4}			Light sweeping, fans on for circulation	
3.3×10^{-8}	2.2×10^{-7}	4×10^{-6} to 2×10^{-5}	10	3.00	Cleanup following accidental failure of plutonium glove box	Ikezawa et al. 1980
1.9×10^{-10}	2.5×10^{-10}	2×10^{-8}	10.9	3.15	**Plutonium oxide** No movement	Jones and Pond 1967
9.5×10^{-8}	1.2×10^{-7}	1×10^{-5}			14 steps/minute	
4.8×10^{-7}	6.1×10^{-7}	5×10^{-5}			36 steps/minute	
1.9×10^{-10}	2.5×10^{-10}	2×10^{-8}			**Plutonium nitrate** No movement	
9.5×10^{-9}	1.2×10^{-8}	1×10^{-6}			14 steps/minute	
4.8×10^{-8}	6.1×10^{-8}	5×10^{-6}			36 steps/minute	
4.2×10^{-8}	4.8×10^{-8}	2.5×10^{-6}	20	3.00	Alpha, no work	Khvostov and Kostyakov 1969
3.3×10^{-8}	3.9×10^{-8}	2.0×10^{-6}			Beta, no work	
3.7×10^{-6}	4.3×10^{-6}	2.2×10^{-4}			Alpha, floors scrubbed with cotton	
1.1×10^{-5}	1.3×10^{-5}	6.8×10^{-4}			Beta, floors scrubbed with cotton	
2.4×10^{-9}	2.4×10^{-6}	9.0×10^{-4}	0	1.22	Maximum value of measurements made while banging on floor	Shapiro 1970
1.4×10^{-6}	2.0×10^{-6}	2.2×10^{-4}	9.0	2.59	**100 steps/minute, contaminated floor** Personal air samplers	Tagg 1966
3.8×10^{-7}	5.4×10^{-7}	5.9×10^{-5}			Area air samplers	
3.2×10^{-6}	4.5×10^{-6}	4.9×10^{-4}			**100 steps/minute, contaminated clothing** Personal air samplers	
2.1×10^{-6}	2.9×10^{-4}	3.2×10^{-5}			Area air samplers	

Table 9-12. Indoor Resuspension Rates Calculated and Compiled by Argonne National Laboratory[a] (continued)

Resuspension Rate (1/s)		Resuspension Factor (1/m)	Air Exchange Rate (1/hr)	Room Height (m)	Conditions	Source
Minimum	Maximum					
2.8×10^{-10}	NA	NA	0.3	2.4	0.3-0.5 µm	Thatcher and Layton 1995
1.2×10^{-10}	NA	NA			0.5-1 µm	
5.0×10^{-9}	NA	NA			1-5 µm	
2.3×10^{-8}	NA	NA			5-10 µm	
1.1×10^{-7}	NA	NA			10-25 µm	
9.4×10^{-9}	NA	NA			> 25 µm	

Note:
[a]Biwer et al. 2002: Resuspension rates calculated and considered by ANL for the RESRAD-BUILD computer code

Legend:
NA = nonapplicable

9.2.3.3 Respirable Fraction (f_{resp})

9.2.3.3.1 Particle size

The f_{resp} modifies the resuspended particle concentration to account only for particles that are respirable. This parameter is used when particle size-specific resuspension rates are not available, as is the situation at this time.

Respirable particles are those that can be inhaled through the nose or mouth. There is a minor discrepancy in the literature and between organizations concerning the particle size description of respirable particles (see table 9-13). The reason is due in part to the different purpose and sampling devices selected for measuring particle size distribution (USEPA 2004a). However, the general consensus is that respirable particles are those that can penetrate and deposit in the alveolar region and are less than or equal to 10 µm in diameter.

Table 9-13. Particle Size Description Used by Various Agencies

Agency/Source	Particle Size Description[1]	Comments
USEPA Office of Air and Radiation[2]	• Inhalable coarse particles: particles > 2.5 µm but < 10 µm in diameter • Fine particles: particles ≤ 2.5 µm	This USEPA office is concerned about health problems associated with particles 10 µm or less in diameter. The term "respirable" is not used.
USEPA Office of Radiation and Indoor Air[3]	• Respirable particles: those that penetrate and deposit in the alveolar region of the lungs—only particles with aerodynamic diameter (AD or AED) ≤ 10 µm	This USEPA office implements the agency's indoor environments program, which is a nonregulatory program that addresses indoor air pollution.
USEPA Environmental Criteria and Assessment Office (ECAO); Office of Health and Environmental Assessment (OHEA)[4,5]	• Inspirable particles: particles that can enter through the nose or mouth • Thoracic particles: particles that can penetrate beyond the terminal larynx into the tracheobronchial region • Respirable particles: particles that penetrate past the tracheobronchial region into the alveolar region	Report does not provide specific particle size range
Canadian Environmental Protection Act (CEPA)[6]	• Thoracic (or respirable) particles: particles that can be inhaled into the tracheobronchial and alveolar regions. Applies to particles ≤ 10 µm in diameter. Subdivided into: ° Fine particles: ≤ 2.5 µm ° Coarse particles: > 2.5 µm but ≤ 10 µm	Document states "Inhalable particles" generally applies to particles ≤ 15 µm in diameter even though the term has been used to describe particles ≤ 10 µm.

Table 9-13. Particle Size Description Used by Various Agencies (continued)

Agency/Source	Particle Size Description[1]	Comments
American Conference of Governmental Industrial Hygienists[7]	• Inhalable particles: "materials that are hazardous when deposited anywhere in the respiratory tract"—aerodynamic diameter ≤ 100 µm • Thoracic particles: "materials that are hazardous when deposited anywhere within the lung airways and the gas-exchange region"—aerodynamic diameter ≤ 25 µm • Respirable particles: "materials that are hazardous when deposited in the gas-exchange region"—aerodynamic diameter ≤ 10 µm	The ACGIH® develops guidelines for workplace exposures. Collection efficiencies associated with specific particle size and for each mass fraction are used.
U.S. Nuclear Regulatory Commission[8,9]	• Respirable particles: aerodynamic diameter ≤ 10 µm	
Lewis et al. 1999	• Inhalable particles: particles < 10 µm • Respirable particles: particles < 2.5 µm	

Notes:
[1] Even when not stated, the diameter usually refers to the AD or AED, which is the diameter of a spherical particle with a density of 1 g/cm^3 that has the same settling velocity in the gas (for example, air) as the particle of interest.
[2] USEPA 2007e
[3] USEPA 2007b
[4] ECAO/OHEA is now the National Center for Environmental Assessment (NCEA), which is part of the Office of Research and Development.
[5] USEPA 1994
[6] CEPA 1999
[7] ACGIH® 2007
[8] Biwer et al. 2002
[9] Yu et al. 2003

Factors that affect indoor air particle distribution are basically the same as those that impact the parameter R. Therefore, it is not surprising that data on the fraction of respirable particles in the air resulting from a resuspension activity are equally lacking. Even though studies have been conducted to determine sources of indoor particles, which include particle resuspension, results from these experiments are not particularly useful for the purposes of this TG because results are reported either as air concentrations or particle generation rates with units of mass per time. Such data permit a comparison of the strength of each source relative to one another, but usually do not include enough information to correlate the air concentration generated from each resuspension activity to the surface concentration.

In light of the lack of data to correlate particle size distribution to a resuspension activity, the best alternative for estimating the fraction of respirable particles is to use data measured from indoor surfaces. But use of such data is not without limitations. One reason is that settled particles probably have a higher likelihood of being disturbed by human activity, which can break up

larger particles. Therefore, it is reasonable to presume size distribution of settled particles would not be entirely representative of the size distribution of resuspended particles. However, this uncertainty may be balanced by the method used to collect settled particles which is likely to break up larger particles, probably even more so than normal human activities. Size distribution of settled particles is usually determined by vacuuming the surface and then passing the collected dust through sieves (Lewis et al. 1999; Mølhave et al. 2000). Thus using size distribution data of settled particles to approximate that of resuspended particles is not expected to grossly overestimate or underestimate the respirable fraction. Other uncertainties and limitations are discussed at the end of this subsection.

Table 9-14 summarizes size distributions for settled dust reported from two sets of measurements, one taken from suburban homes and the other from offices. These data by no means represent the indoor particle concentration for all homes or offices but provide a general sense of the size distribution of settled particles. Data show most settled particles are larger than 25 µm in diameter ((fine beach sand is about 90 µm in diameter (USEPA 2007a)). Other studies that use larger particle size range support this trend. Que Hee et al. (1985) and fellow researchers reported 82 percent of particles were larger than 44 µm in diameter for dust collected from one Cincinnati home. Similarly, Lioy et al. (2002), reported that only 0 to 20 percent of total particles collected were less than 75 µm in diameter.

Data in table 9-14 also show homes have a slightly higher fraction of particles less than 25 µm than do offices. Lewis et al. did not report the fraction for particles less than 10 µm, but estimated 0.7 percent of particles were less than 4 µm. This fraction is almost the same as the 0.6 percent estimated by Mølhave et al. for all particles less than 10 µm. One reason why homes have a higher fraction of particles in the smaller size range than do offices is the source of particles. For example, cooking produces ultrafine particles ($d \leq$ µm), and smoking is a significant contributor of particles in the 2.5-µm size range, but these sources are generally absent from office environments (Long et al. 2000; Na and Cocker 2005; Fisk et al. 2000). Other factors that affect size of indoor particles include building material and ventilation/filtration systems.

Table 9-14. Indoor Surface Particle Size Distribution Data

Particle Size Range (µm)	Suburban Homes	Offices
	Percent by Weight (%)	
0–10	NA	~ 0.6
< 4 µm	0.7	NA
< 25	20.7	~ 6.9 (incl. 0-10 µm)
≥ 25	79.3	93
Comments	• Dust collected from 25 suburban homes in North Carolina; approximately 30–40 minutes of vacuuming per home • Typical home: two-story, 185 m^2 average floor area, about 80% carpeted, forced-air ventilation, gas heating units, and electric stoves • Total gross weight, incl. vacuum bags = 6.35 kg	• Dust collected from seven offices in Denmark; each office vacuumed once/week during an 8- to 10-week sampling period, with normal cleaning in between • General office characteristics: 13,000 m^2 floor area, 4.0 air changes per hour, 1,050 occupants • 30-gram samples
Reference	Lewis et al. 1999	Mølhave et al. 2000

For this TG, a default value of 10 percent (rounded up from 6.9 percent estimated for particles < 25 µm) is recommended even though measurements by Mølhave et al. showed only 0.6 percent of particles in offices were in the respirable range. This is a conservative estimate but takes into account the limited data set and the fact that results are based on offices in Denmark. Although Mølhave et al. indicated experimental conditions are representative of normal offices there, without a comparison of building code requirements and indoor characteristics, it is unknown whether they are representative of office environments in the U.S.

The default respirable fraction of 0.1 (10 percent) should only be applied when size-specific R is not available. If size-specific R values are used, then f_{resp} should be set equal to 1 (100 percent).

9.2.3.3.2 Uncertainties and limitations

Risk assessors should keep the following uncertainties and limitations in mind when applying the default f_{resp}. Some of the uncertainties and limitations identified for the parameter R also apply to f_{resp}.

• Experimental studies usually composite dust samples collected from several different buildings; therefore, the effect of dust loading on particle size distribution is unknown. It seems reasonable to assume the particle size fraction is not expected to vary significantly between

different dust loadings because smaller particles on dustier surfaces probably have a tendency to stick together. If so, the fraction of particles in the respirable range would remain low in comparison to the fraction of nonrespirable particles.

• Due to the lack of data, the current default f_{resp} assumes size distribution of settled particles is similar to that of particles measured in the air after a resuspension activity. However, these fractions are not expected to be significantly different because the surface collection method probably "breaks up" particles the same way as resuspension activities.

• Butte and Heinzow (2002) indicated there is no standardized method for collecting dust samples, which makes comparison between results more difficult. For example, Mølhave et al. (2000) collected dust over an 8-to-10-week sampling period and permitted normal activities in each office to take place in between sampling. By contrast, Que Hee et al. (1985) estimated particle size from one dust sample from a single home.

• The default respirable fraction is only applicable under normal conditions and should not be applied to estimate exposures following events such as explosions or building collapse.

• Particles that are inhalable through the nose/mouth but not small enough to penetrate the lungs may deposit along other parts of the respiratory tract. Some toxicity values are based on the nose as the target organ. For example, the reference concentration for vinyl acetate is based on nasal epithelial lesions observed in laboratory animals (USEPA 1990). However, most of these toxicological studies were conducted using a gaseous/vaporous form of the substance. In addition, particles deposited along the upper respiratory tract are generally cleared more rapidly; therefore, long-term effects associated with inhalation of particles are primarily associated with retention in the lungs or absorption through the lungs.

9.2.3.4 Deposition Loss Rate (λ_{dep})

9.2.3.4.1 Deposition coefficient factors

The deposition loss rate, λ_{dep} or deposition coefficient, is the rate at which airborne particles are removed from the air as they deposit onto indoor surfaces. As with particle resuspension, particle deposition is affected by both particle (for example, size, density) and room characteristics (for example, turbulence, surface geometry) (USEPA 1997c). For example, Thatcher et al. (2002) observed increased particle deposition after furnishing a previously bare room with furniture that added 12 m^2 of surface area. The researchers also noted that the orientation of the deposition surface affected particle deposition. Particles that deposit primarily

by gravitational settling (particles between 1 and 5 µm) were less affected by vertical and downward facing surfaces than smaller particles that deposit by diffusion (d < 0.1 µm) (Thatcher and Layton 1995; Thatcher et al. 2002). Larger particles are also expected to deposit faster, as consistently demonstrated by results from several studies (Howard-Reed et al. 2003; Thatcher et al. 2002). Thatcher et al. (2002) noted particles larger than 10 µm were settling out "too quickly" for them to make accurate estimates of the deposition loss rates. While particle size seems to have the greatest influence on particle deposition, one surprising finding by Howard-Reed et al. (2003) is that particle composition has little effect on particle deposition. Assessing the deposition of fine and coarse particles generated from cooking (frying and sautéing), burning a citronella candle, and pouring kitty litter, the authors observed comparable deposition rates under similar test conditions (for example, fan off/on).

Other than room and particle characteristics, particle deposition rates may also be affected by experimental factors (Howard-Reed et al. 2003). Howard-Reed and her colleagues noted greater variability among deposition rates, especially for particles between 0.3 to 0.7 µm, estimated from controlled environments such as test homes or chambers. They noted such measurements could be an order of magnitude smaller than those estimated from occupied homes. Similarly, sampling equipment could affect results. For example, an Aerodynamic Particle Sizer or APS reportedly has a tendency to mix particles larger than 4.5 µm with smaller particles, resulting in a lower count for larger particles (Howard-Reed et al. 2003). In another study, deposition onto fan blades accounted for 9 to 13 percent of the particles removed from a room (Thatcher et al. 2002). However, the authors concluded the amount deposited onto the fan blades was not significant enough to explain the notably higher deposition loss rates observed with increasing air speed.

Deposition loss rate may be estimated from experimental studies if the major types of indoor particle losses are known. For example, Thatcher and Layton (1995) estimated λ_{dep} by measuring the concentration of suspended particles in the air at short time intervals and subtracting out particle loss by exfiltration. Loss from particle deposition is sometimes described using a deposition velocity, which is a function of λ_{dep} and the room surface-to-volume ratio (Thatcher and Layton 1995; Biwer et al. 2002).

Equation 9-8

$$\lambda_{dep} = \frac{A_d \cdot v_{dep}}{V}$$

Where:

λ_{dep} = deposition loss rate (1/hr)
A_d = deposition area (m^2)
V_{dep} = deposition velocity (m/hr)
V = room volume (m^3)

Since literature values of V_{dep} are usually derived by applying the surface-to-volume ratio from either experimental (for example, Thatcher and Layton 1995) or assumed conditions (for example, Biwer et al. 2002), it is more preferable to use λ_{dep} as opposed to V_{dep}. However, measured values of λ_{dep} will undoubtedly be affected by the size of the room and available deposition area as well as other factors.

Actual measurements of indoor particle deposition loss rates are few. Howard-Reed et al. (2003) identified just over 20 studies that evaluated deposition rates for particles greater than 3 µm. The authors included summaries of experimental conditions and deposition loss rates from 10 studies, some of which are shown in table 9-15. Loss rates from other studies, as well as those estimated by Howard-Reed et al., are also tabulated below.

Table 9-15. Particle Deposition Loss Rates

Source	Particle Size (µm)	Deposition Loss Rate (1/hr)	Experimental Conditions
Offerman et al. 1985[a]	0.3 1.5	0.05 0.38	• One room of a three-room, unoccupied test house • Cigarette smoke generated by machine
Xu et al. 1994[a]	0.3 – 1.5	0.1 – 1.2 (fan off) 0.4 – 2.3 (fan on)	• One room of experimental house • Cigarette smoke generated by machine
Thatcher and Layton 1995	1 – 2 2 – 3 3 – 4 4 – 6	Days 1 and 2 0.25 – 0.28 0.55 – 0.75 0.77 – 0.84 1.68 – 1.78	• Occupied two-story home in California • Vigorous house cleaning activities • Assumed all deposition occurred on floor surface
	1 – 5 5 – 10 10 – 25	Day 3 0.46 1.36 2.36	
Wallace 1996[b]	$PM_{2.5}$ PM_{10}	0.39 0.65	Based on measurements in nearly 200 residences
Wallace et al. 1997[a]	0.4 - >10	Avg 0.20 – 2.8	• Occupied home • 27 days of data
Fogh et al. 1997[a]	0.5 – 5.5	Avg 0.33 – 1.77 (unfurnished) Avg 0.47 – 1.88 (furnished)	• Four houses, some occupied • Monodispersed particles from particle generator

Table 9-15. Particle Deposition Loss Rates (continued)

Source	Particle Size (µm)	Deposition Loss Rate (1/hr)	Experimental Conditions
Abt et al. 2000b	0.02 – 0.5 1 – 10	Avg 0.7 – 1.11 Avg 0.97 – 3.02	Four Boston homes, occupied
Emmerich and Nabinger 2001[a]	0.3 – 5	Avg 0.4 – 1.0 (HVAC fan off) Avg 0.74 – 2.0 (HVAC fan on)	• Unoccupied test house • HVAC fan off/on
Long et al. 2001	0.02 – 0.03 0.4 – 0.5 0.7 – 3 $PM_{2.5}$	Avg 0.35 Avg 0.10 0.22 – 0.66 0.15, 0.10 (summer, winter)	• Nine Boston homes • Cooking, other scripted activities • Particle loss estimated from data measured during non-source period (that is, nighttime)
Vette et al. 2001[a]	0.3 – 0.6 0.75 – 0.85	0.45 – 0.6 1.3	• Unoccupied detached home • Large uncertainties reported for particles >1 µm
Thatcher et al. 2002	Median size 0.55 – 1.0	0.10 – 0.20 (bare) 0.11 – 0.25 (carpeted) 0.20 – 0.38 (furnished)	• Tightly sealed, experimental room: 2.2 x 2.7 x 2.4 m^3 • Test conditions involved three levels of furnishing (bare, carpeted, furnished); four air speeds (0, 5.4, 14.2, 19.1 centimeters/second) • Polydispersed olive oil "particles"
	1.24 – 2.37	0.18 – 1.27 (bare) 0.18 – 1.45 (carpeted) 0.29 – 1.60 (furnished)	
	2.94 – 5.62	0.92 – 6.65 (bare) 1.02 – 5.79 (carpeted) 1.30 – 6.59 (furnished)	
	6.98 – 8.66	4.29 – 12.60 (bare) 3.97 – 11.60 (carpeted) 4.12 – 11.60 (furnished)	
Howard-Reed et al. 2003	0.3 – 2.5	Avg 0.29 – 0.88 (HVAC fan off) Avg 0.81 – 2.0 (HVAC fan on)	• Three-story, occupied townhouse; total volume = 400 m^3; floor area ~ 50 m^2 per level • Three indoor activities: cooking, burning a candle, pouring kitty litter • HVAC fan off/on, with and without filter • Kitty litter poured in sealed basement
	2.5 -5.0	Avg 1.1 – 1.5 (fan off) Avg 3.0 (fan on)	Results based on candle and kitty litter only
	5.0 – 10	Avg 2.7 (fan off) Avg 4.8 (fan on)	Results based on kitty litter only
	> 10	Avg 5.2 (fan on) Avg 7.1 (fan off)	

Notes:
[a] Summary of results as reported by Howard-Reed et al. 2003
[b] USEPA 1997c

Legend:
HVAC = heating, ventilation, and air-conditioning

As the data show, estimated λ_{dep} of particles less than 10 µm vary from less than 1 to 12.6 hr^{-1}. While experimental conditions clearly have an influence on particle deposition, particle size appears to have a greater effect. For example, for particles between 0.3 to 5.0 µm, Howard-Reed et al. estimated average deposition loss rates of 0.29 to 1.5 hr^{-1} when the fan in the townhouse's central heating, ventilation, and air-conditioning (HVAC) unit was turned off. With the fan on, average loss rate increased to 0.81 to 3.0 hr^{-1}. These values are somewhat comparable to the ranges of 0.4 to 1.0 hr^{-1} (fan off) and 0.74 to 2.0 hr^{-1} (fan on) estimated by Emmerich and Nabinger for the same size range even though different experimental conditions were used. However, greater variability is seen when comparing λ_{dep} by particle size, as evident in results from Long et al. (2001), Thatcher et al. (2002), and Howard-Reed et al. (2003). It is for this reason that Thatcher et al. (2002) argues against using a single λ_{dep} to represent the deposition loss for "integrated mass measurements" (that is, PM_{10}).

At this time, this TG does not provide λ_{dep} values for different particle sizes even though data clearly show very different deposition loss estimates for particles less than 10 µm. The main reason is the lack of size-specific data for other parameters needed in equation 9-5 or equation 9-6. Even when particle-specific data becomes available, it will first be necessary to analyze the data to select size bins that best fit particle characteristics for all parameters.

Since values of λ_{dep} vary by a large margin, choosing a single value for making point estimates is difficult. However, the objective is to apply consistent and reasonable assumptions throughout this TG, not to select the value that provides the "most conservative" estimate. Based on previous discussions of particle resuspension and fraction respirable, larger particles are more likely to be resuspended than smaller particles, possibly because of the low fraction of particles <10 µm compared to particles larger than 25 µm. Recall Mølhave et al. (2000) estimated less than 0.1 percent of settled particles in offices were less than 10 µm. Of this already small fraction, only 17 percent were less than 3 µm (or 0.1 percent of total particles, not just of the PM_{10} fraction). Therefore, although smaller particles linger in the air longer as they do not deposit as quickly as larger particles, it would be inconsistent to select a deposition loss rate for particles that only represent a small fraction of the particles resuspended, even when considering only the respirable fraction.

Other factors to consider when selecting a value of λ_{dep} are the experimental conditions. Since all occupied offices are expected to have some kind of ventilation, selecting values estimated from "fan off" experiments are not realistic. Thatcher et al. (2002) suggested studies involving low ventilation (air exchange below 0.1 hr^{-1}) are more useful for "academic interest only" as such conditions rarely occur outside of experimental settings. In addition, occupied offices will have some furniture in place. Thus, λ_{dep} values should ideally be based on studies that have some furniture in the room.

Based on all that has been discussed thus far, data by Thatcher and Layton (1995) and Howard-Reed et al. (2003) were evaluated closer as these data sets provide λ_{dep} for different particle size range and were estimated from occupied homes. Thatcher's more recent study was not considered at this time because the study was conducted by placing fans in an experimental room, and it is unknown how those fan speeds correlate to actual air flow generated by HVAC units. Results from that study, however, provide a good understanding of the effects of ventilation on particle deposition. Table 9-16 summarizes λ_{dep} values considered for selection of a deterministic value for respirable particles. Estimates for smaller particles were not included because indoor data show only a small fraction of particles are less than 4 µm.

Table 9-16. Summary of Studies Used to Select a Deterministic Value for the Deposition Loss Rate

Source	Particle Size Range (µm)	λ_{dep} (1/hr)
Thatcher and Layton 1995	3 – 4 4 – 6 5 – 10	0.77 – 0.84 1.68 – 1.78 1.36
Howard-Reed et al. 2003	2.5 – 5.0 5.0 – 10	Avg 3.0 (fan on) Avg 4.8 (fan on)

Values of λ_{dep} for particles between 5 to 10 µm vary from 1.36 to 4.8 hr^{-1} but Thatcher and Layton's estimate is lower than the λ_{dep} estimated for particles between 4 to 6 µm. Due to the lack of data, a single default value of 3.0 hr^{-1} is arbitrarily selected for estimating the resuspended particle concentration. This value is based on the average λ_{dep} estimated by Howard-Reed et al. for particles between 2.5 to 5 µm, with the HVAC fan on but no in-duct filter. Compared to the default deterministic value of 14.8 hr^{-1} suggested by Yu et al. (2003) for the RESRAD model, this value is low (converted from a deposition velocity of 0.01 meters per second (m/s) using equation 9-8 and an area/volume ratio of 1/2.438 m^{-1} which is based on an 8-foot ceiling as assumed by Yu et al. (2003)). However, it still falls within the recommended minimum and maximum values (0.004, 4 hr^{-1}) of a default log-normal distribution recommended for the RESRAD model (converted from deposition velocities of 2.7×10^{-6} and 2.7×10^{-3} m/s using the assumptions in Yu et al. (2003)).

9.2.3.4.2 Uncertainties and limitations

Literature data of λ_{dep} values were narrowed by excluding estimates from experimental environments and by focusing on studies that provide particle size information in order to select a value that corresponds with the predominant particle size fraction. However, the resulting

default λ_{dep} is still an arbitrary value. The risk assessor should understand the assumptions and limitations associated with this default, and make adjustments as appropriate or at least provide a qualitative discussion of major uncertainties when applying the default λ_{dep}.

• Experimental data clearly show λ_{dep} varies even for particles within the respirable range (< 10 μm). Thus, choosing a single value to represent the deposition loss for all particle size potentially leads to overestimation of the airborne concentration for larger particles and underestimation of the airborne concentration for particles that deposition by diffusion. Since the fraction of particles less than 3 μm is very small, underestimation of the airborne concentration of particles in this size range is not expected to be significant. When more data become available, the data should be evaluated to assess effective particle size bins so that λ_{dep} corresponding to each bin can be assigned.

• Data from studies that simulate an office environment are lacking. However, as observed by Howard-Reed and her colleagues, particle source has little effect on particle deposition. If true, this would eliminate one major difference between an office and a residence. Another major difference is building ventilation. Since particle deposition is proportional to ventilation, values estimated from homes are expected to be lower than offices because offices tend to have more elaborate and efficient HVAC systems than homes. However, the effect of ventilation on particle deposition is expected to be less significant than that of particle size alone.

• This TG is intended for assessing long-term exposures and assumes HVAC units, on average, operate normally. If the user is interested in short-term exposures when HVAC units are not in operation, the user ought to consider whether λ_{dep} should be adjusted to account for reduced room ventilation.

• As shown by Thatcher et al. (2002), measurements of λ_{dep} are affected by the size of the available deposition area. Since the degree of furnishing is a highly variable factor, it is not possible to totally eliminate uncertainties caused by this factor. However, values of λ_{dep} should be based on studies that include some furnishing in the room, not an empty room.

9.2.3.5 Room Volume (V)

9.2.3.5.1 Mixing volume factors

Room volume or mixing volume, V, is used to estimate the amount of particles removed by the room's air flow. Very little information on office volume is available, but this parameter can be estimated by multiplying typical office area by the room height. According to equation 9-5, as the mixing volume increases, the air concentration decreases; thus, a default mixing volume

should be estimated using the smallest likely work area. As discussed earlier, many of today's workspaces are open-plan offices divided by panels that typically range from about 3 to 7 feet tall. For the purposes of mixing volume consideration, cubicles with tall panels, arbitrarily selected to be greater than 5 feet, are treated similarly to private offices with doors. Although particles may be transported out of a cubicle's open spaces (such as those from the top of panels to the ceiling and entrance), the effectiveness of air flow depends on ventilation supply and return to the cubicle. Since all offices are laid out differently, cubicles of the same dimension may have a smaller mixing volume than others.

The Energy Information Administration (EIA), which is part of the DOE, provides office workspace areas based on statistics compiled from its energy consumption surveys (EIA 2006b). However, reported mean (434 square feet (ft^2)) and medium (525 ft^2) workspaces from the 2003 survey are much higher than office standards used by many organizations to allocate workspace (EIA 2006a; Voss 2000). Values reported by the EIA are probably higher because workspaces were estimated by dividing total floor space by the number of workers in the building. Since total floor space included unoccupied offices and possibly non-work areas, final estimates are higher than actual workspace. For this reason, workspace data provided by the EIA were not used in this TG.

Although the U.S. has no regulatory office space standards, many companies or agencies have developed their own guidelines. According to data published in 1997 by the International Facility Management Association (IFMA), 31 percent of the organizations who participated in a survey managed their workspace using consistent written standards (Voss 2000). This figure has probably increased since that survey was conducted. Citing results from the same survey, Voss (2000) noted U.S. space standards ranged from 73 ft^2 for general clerical workers to 280 ft^2 for upper management. This is somewhat consistent with space standards and workspace recommendations offered by office workspace consultants, although upper management such as Corporate Executive Officers or CEOs are commonly allocated private office spaces of about 400 ft^2. In addition, typical office size may have decreased since the IFMA survey cited by Voss. Today, workspaces of 48 to 64 ft^2 or even 36 ft^2 are not uncommon (BuyerZone.com® 2007, Young 2007). (BuyerZone.com® is a registered trademark of BuyerZone.com, Inc., Watertown, Massachusetts.)

Table 9-17 provides some office workspace recommendations obtained mostly from office space consulting companies. Only workspace recommendations for the smallest office are listed, but if recommendations for private offices and cubicles were available, workspaces for both types of offices are included. In addition, when different workspace dimensions were provided for a specific office type, only the lowest end of the range is included.

Table 9-17. Examples of Office Work Space Allocation

Source	Office Size[a]		Type[b]
BuyerZone.com® 2007[c]	36 ft^2	(3.3 m^2)	• Cubicle
OfficeFinder™ 2007[d]	60 ft^2 100 ft^2	(5.6 m^2) (9.3 m^2)	• Open space, clerical or secretary • Private office, executive
Corporate Real Estate Advisors 2007[e]	36 ft^2 120 ft^2	(3.3 m^2) (11 m^2)	• Cubicle, sales • Private office, middle management
Bonneville Power Administration 2002[f]	48 ft^2 72 ft^2	(4.5 m^2) (6.7 m^2)	• Students, contractors, visitors • Secretaries
Corporate Facilities Group, Inc. 2007[g]	50 ft^2 100 ft^2	(4.7 m^2) (9.3 m^2)	• Partitioned open space, clerical • Employee private office
Fennie 2005	36 ft^2	(3.3 m^2)	• Cubicle, administrative

Notes:
[a]Only the smallest office size is listed in this column. If the source provides a range, value shown is the low end of the range.
[b]If the source did not state whether the office is a cubicle or a private office, this information was left out.
[c]http://www.buyerzone.com/
[d]http://www.officefinder.com/ (OfficeFinder™ is a trademark of OfficeFinder LLC, Sammamish, Washington.)
[e]http://www.merchantcircle.com/business/Corporate.Real.Estate.Advisors
[f]http://www.bpa.gov/corporate/
[g]http://www.corporatefacilitiesgroup.com/

As table 9-17 shows, a workspace that is 36 ft^2 is commonly recommended for an organization's administrative staff. However, professional and technical office workers are now commonly assigned offices as small as 36 ft^2 (Voss 2000). While administrative workers tend to work in open areas because the nature of their job involves greater interaction with other employees, other types of workers may have offices surrounded by taller cubicle walls that offer more privacy. Therefore, a default office workspace of 36 ft^2 (3.3 m^2) was used to estimate the mixing volume. If an office area does not have cubicles, then the smallest private office of 100 ft^2 (9.3 m^2) could be used.

In order to estimate the mixing volume, the room area must be multiplied by the room height. Some authors include the plenum, which is the space that houses piping, wiring, or ductwork, when discussing the ceiling height (see for example, Fisk et al. 2000 and Dols et al. 1995). For the purposes of this TG, room height is defined as the distance from the floor to the "dropped" ceiling, which excludes the plenum.

No data for typical office room heights are available. However, the Exposure Factors Handbook (USEPA 1997b) states a ceiling height of 12 ft (~3.7 m) is typical for commercial buildings. The Exposure Factors Handbook does not indicate whether this generality includes the plenum. Until more information on typical office room height is available, it is assumed this "typical" ceiling height excludes the plenum. Thus, a height of 12 ft was used to estimate the mixing volume. Combining the height and the surface area gives a mixing volume of 432 cubic feet (12 m^3).

9.2.3.5.2 Uncertainties and limitations

The risk assessor should consider the following uncertainties and limitations and determine whether the room volume should be adjusted to meet the user's set of exposure conditions.

• The room or mixing volume is used to estimate the amount of resuspended particles removed by the room air flow; therefore, as the room volume increases, the air concentration decreases. If the room volume being assessed is smaller than the default volume of 12 m^2, then the resuspended air concentration could potentially be underestimated. The opposite is true of room volumes that are much larger than the default volume.

• The default room volume is based on information for office environments only. Typical floor space for other types of use (for example, warehouses) or homes will be different from the default room volume recommended here. If a risk assessor requires specific data for other building types, they could consult the EIA, which compiles energy statistics for homes and other commercial buildings. The Exposure Factors Handbook also provides some information on residential building characteristics.

• The default mixing volume was estimated from a work area typically recommended for cubicles but a room height typical of commercial buildings. This assumes the cubicle is divided by panels that almost reach the ceiling. As the text notes, panels typically range from 3 to 7 feet. Assuming the cubicle is confined within this space conservatively limits the mixing volume. If cubicles have large spaces above the panel top or are well ventilated, the risk assessor should consider selecting a different workspace (for example, 100 ft^2 for private offices). For open-plan offices where workspaces are minimally divided or partitioned by short panels, the entire office floor space should be used.

9.2.3.6 Source Area (A_s)

9.2.3.6.1 Source area factors

The source area serves as the reservoir of contaminated particles available for resuspension. Particles deposited on any surface—vertical or horizontal, smooth or porous—may be resuspended when disturbed. For estimating long-term exposures, consideration should be given to those surfaces with which the exposure scenario is likely to come in frequent contact. For the office worker, these surfaces are most likely horizontal surfaces, such as desk tops, including objects laying on the horizontal surface. Although particles could also resuspend from the floor, current surface sampling results are limited to wipes of smooth, nonporous surfaces. Since most offices are carpeted, these results would not be representative of the contaminant load on carpets.

According to equation 9-6, source area is linearly related to the mixing volume. Recall from paragraph 9.2.3.5 that mixing volume can be estimated by multiplying room area by the room height. This means a fractional increase in source area relative to the office area always results in the same increase in estimated air concentration as long as all other parameters remain unchanged. For example, the resulting air concentration for a small 3.3 m^2 office that has 1.65 m^2 of horizontal surface (for example, desk top, shelves) is the same as a 100 m^2 office with 50 m^2 of horizontal surface. In both cases, the fraction of source area relative to the office floor area is 50 percent. This relationship simplifies the difficulty of trying to determine whether to estimate a source area based on surfaces available in individual offices versus a wide-open office area. Using a default percentage relative to the workspace ensures the risk assessor does not forget to adjust the source area if the workspace is modified.

For this TG, the default source area is assumed to be 60 percent of the workspace as determined in paragraph 9.2.3.5. This is an arbitrary value based on observations of how offices are normally furnished. While it is possible for horizontal surfaces to exceed the floor area, in most cases, even when taking into account staggered surfaces such as shelves placed above work spaces, total exposed horizontal surfaces usually do not exceed the floor space. Additionally, office workers rarely come in constant contact with all surfaces in the office even when considering long-term exposures. However, unlike direct dermal contact which requires actual skin contact with the surface, particles settled in remote corners may be resuspended without direct contact if the resuspension activity is intense enough. The 60-percent fraction also assumes particles deposited on other objects (for example, paper piles and other clutter) are equally likely to be resuspended from office worker activities. Based on the office area estimate from paragraph 9.2.3.5, 60 percent of 36 ft^2 is 22 ft^2.

9.2.3.6.2 Uncertainties and limitations

Although the parameter A_s is rather straight-forward, the following issues should be kept in mind when applying the recommended default source area.

• Actual source area may be smaller or larger than 60 percent of the floor space. In addition, particle resuspension from floors was not considered at this time because most offices are carpeted and current DEHE wipe sampling protocol is limited to wipes of smooth, nonporous surfaces. However, when surface sampling data for carpet become available, a similar fraction could be applied to estimate the amount of exposed floor space. Resulting air concentration would be a summation of particles resuspended from smooth surfaces and particles resuspended from the floor.

• Wipe samples are taken only from a surface, not objects on the surface. Although particles deposited onto objects (for example, documents) are also capable of being resuspended, it is unknown whether the loading on the surface is similar to the loading on these objects.

9.2.3.7 Air Exchange Rate (λ_a)

9.2.3.7.1 Air exchange factors

Air exchange rate is the number of times air in a room or building is replaced (USEPA 1997c; USEPA 2005c). As used in equation 9-5, λ_a reduces the average indoor concentration in a room or building. This parameter is typically expressed in units of air changes per hour (ACH), where one ACH in a room means the total volume of air in that room will be replaced in 1 hour. However, this applies only in theory as uniform mixing is hard to achieve (USEPA 1997c). The degree of mixing depends on the process by which indoor air exchange occurs: infiltration of outside air (for example, cracks); natural ventilation (for example, open window); and forced or mechanical ventilation (USEPA 1997c; Biwer et al. 2002). In addition, environmental conditions also affect indoor air exchange (USEPA 1997c; Biwer et al. 2002). Researchers who have measured ventilation rates in homes recorded higher λ_a during the summer and from homes located in warmer regions (USEPA 1997c; Biwer et al. 2002). The USEPA notes this trend is consistent with the expectation that people open windows when it is warm outside, but also cautions λ_a in the same regions could be reduced during very hot months when homeowners switch to air-conditioning as opposed to natural ventilation for cooling.

The indoor environment of most commercial buildings is controlled by some type of HVAC system (EIA 2006b; Institute of Medicine (IOM) 2000). Of 100 randomly selected office buildings assessed in a building survey conducted by the USEPA, only 3 were not mechanically

ventilated (Persily et al. 2005). Some states and many municipalities have building design or state energy codes that specify minimum ventilation rates based on occupancy type (IOM 2000; California Energy Commission 2006). For example, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) publishes ventilation standards that are frequently cited and used for both residential and nonresidential buildings (Barley 2001; USEPA 2007c). However, meeting minimum ventilation requirements is not synonymous with maintaining those minimum ventilation rates during occupancy (Barley 2001; IOM 2000). The IOM points out "most states and municipalities [have] no legal requirements to actually maintain the specified minimum ventilation rates."

Since minimum ventilation standards currently serve more as considerations for HVAC and building designs and are not guarantees of actual indoor ventilation, they are not reliable estimates of λ_a under normal occupancy conditions. Therefore, λ_a measured from commercial buildings were used to estimate typical office ventilation rates. As with other parameters, ventilation data for nonresidential buildings is limited. A review of the literature identified three sources that are cited repeatedly for commercial buildings (see IOM 2000; Thatcher et al. 2001; Johnson 2002; USEPA 2007d). The earliest of these involved ventilation rates measured from 38 commercial buildings in Washington and Oregon (Turk et al. 1989). Building size and occupancy ranged from 860 m^2 for 34 people to 34,300 m^2 for 2,500 people. Using the tracer gas sulfur hexafluoride (SF_6) measurement technique, the authors estimated mean ventilations of 1.5 ACH for offices with floor space less than 9,300 m^2 and 1.8 m^3 for offices larger than 9,300 m^2. Table 9-18 lists ventilation rates estimated by Turk et al.

The second often-cited source is a ventilation survey conducted by Lagus Applied Technology, Inc. (1995) for the California Energy Commission (see IOM 2000; Thatcher et al. 2001; USEPA 2007d). This also used the tracer gas technique to monitor ventilation rates in 49 buildings located in California (Thatcher et al. 2001; USEPA 2007d). Buildings in the survey included small and large offices, retail, and schools.

The research and publications of Persily and his colleagues provide the third most cited sources of commercial ventilation rates. The author's earlier studies consisted of actual ventilation measurements from office buildings (see IOM 2000; Thatcher et al. 2001; Biwer et al. 2002). Persily and fellow researchers recently analyzed data from USEPA's Building Assessment Survey and Evaluation (BASE) study, which contains ventilation rates from randomly selected office buildings in the U.S. (Persily and Gorfain 2004; Persily et al. 2005). The USEPA (2007d) relied on results from these studies to generate and select λ_a distributions for its ozone analysis in support of the current ozone air quality standards. Table 9-18 summarizes Persily's data as cited and used in other studies.

Table 9-18. Summary of Ventilation Rates for Commercial Buildings (Office Data Only)

Source	No. Buildings	Type	Operating Condition	Estimated Ventilation Rate (ACH or hr^{-1})				
				Mean	SD	Median	Min	Max
Turk et al. 1989	8 14 24	Offices < 9300 m^2 Offices > 9300 m^3 All offices	As found	1.5 1.8 1.6	NA	NA	NA NA 0.3	NA NA 4.1
Lagus Applied Technology, Inc. 1995[a]	17 5	Small offices Large offices	Minimum ventilation	1.3 0.8	0.7 0.6	NA	0.3 0.7	2.7 2.7
Persily and Grot 1985[a]	9	Offices	Yearly average	0.7	0.2	NA	0.3	1.1
Persily 1989[b]	14	Offices	Yearly average	0.9	0.3	NA	0.3	1.7
Persily et al. 2005[c]	96	Offices	As found, up to 4 times each day for 2 days	1.96	2.33	1.08	0.071	13.8

[a]As reported in Thatcher et al. 2001 and IOM 2000
[b]As reported in IOM 2000
[c]As used and reported in USEPA 2007d

Legend:
SD = standard deviation

To be consistent with the definition of office buildings used in the commercial energy survey discussed in paragraph 9.2.3.5, table 9-18 only shows ventilation measurements from offices. Except for a minimum ventilation rate of 0.071 estimated by the USEPA using Persily's ventilation analysis of the BASE study, the minimum ventilation rates of 0.3 ACH among all studies are in agreement with each other. This is somewhat surprising considering the difference in monitoring protocol (for example, measurement interval and duration) and HVAC systems. What is interesting is the considerably wider range estimated using Persily's most recent analysis of ventilation rates from the BASE study. Since office buildings were randomly selected for the BASE study, they could be said to be more representative of office buildings in the U.S. Additionally, with 390 ventilation measurements, this data set is much larger than that of the other studies (USEPA 2007d). Despite a maximum λ_a of 13.8 ACH, mean and median ventilations of 1.96 and 1.08 ACH, respectively, indicate unusually high ventilations are not the norm.

Based on the discussion above, a deterministic λ_a of 1.08 ACH is recommended for this TG. This is the median ventilation rate estimated by the USEPA (2007d) using the Persily et al. assessment of data from the BASE study. This value is similar to the deterministic value of 0.8 ACH recommended by Yu et al. (2003) for evaluating radiation exposures in homes and offices and the geometric mean of 1.1094 ACH used by the USEPA (2007d) for its lognormal

distribution of office ventilation in the ozone assessment. Although a distribution of λ_a may be more appropriate than a single value, this TG does not provide distributions for conducting a probabilistic assessment at this time. See below for the uncertainties and limitations associated with using a determinist default value for λ_a.

9.2.3.7.2 Uncertainties and limitations

The risk assessor should consider the following uncertainties and limitations to assess whether to modify the default λ_a or to qualitatively discuss how using a default λ_a affects results.

• A single value of λ_a is recommended in this TG. In reality, building ventilation fluctuates daily or even hourly depending on the various factors discussed above. For long-term exposures, averaged concentrations are generally used to assess potential health impact. Since the default λ_a is intended to represent an average ventilation over time, constant fluctuations would affect final results but are not expected to significantly impact those results. For short-term exposures, however, the user should select other values of λ_a that may be more representative of their exposure conditions (for example, daytime or nighttime).

• Although the default λ_a was selected from data that included measurements from randomly selected offices, this value could overestimate or underestimate λ_a in offices that have significantly different ventilation. If the user knows that a specific building being investigated has a much higher average ventilation than the recommended default, the user could consider modifying this parameter to obtain more realistic results.

• As mentioned earlier, indoor air exchange is affected by the manner in which the building is ventilated. Since data show ventilation varies depending on the method (for example, natural, mechanical), ideally different values of λ_a should be made available based on this and/or other factors. For example, depending on the significance of variation observed from actual measurements, λ_a values could be recommended for office buildings using different office size "bins," number of stories, ventilation method (to include type of mechanical ventilating system), and/or region. The limitation of having a single default λ_a affects only the selection of a deterministic value. For a probabilistic assessment, a single distribution would presumably account for all factors that influence building ventilation.

• Building ventilation measurements are affected by both the sampling protocol and study objectives (USEPA 1997c). For example, the tracers, perfluorocarbon and SF_6 have both been used to estimate indoor ventilation rates. However, the effect of the type of tracer gas and the

estimated air exchange is unknown. The lack of a standard protocol for measuring building ventilation for a stated objective makes it difficult to compare values or to combine values from different studies.

• Although HVAC systems provide ventilation, if improperly designed or improperly maintained, they could also transport contaminants from one area of the building to another. This could increase the overall contaminant concentration in the indoor air.

9.2.4 Inhalation of Semi-Volatiles Sorbed to the Surface

Studies involving pesticides have shown surfaces with good sorptive potential essentially serve as a sink, whereby pesticide in the vapor phase either adsorb onto or absorb into these surfaces. This phenomenon is most notable for semi-volatiles that do not rapidly volatilize and for surfaces with high sorptive potential, such as those made of plastic or foam (Gurunathan 1998). In one study, Gurunathan and fellow researchers observed increased levels of chlorpyrifos on plastic-laminated surfaces beginning at about 72 hours after pesticide application even though no more pesticide was sprayed into the test environments. The authors attributed the increase in surface concentration to the adsorption/absorption of chlorpyrifos volatizing from chlorpyrifos initially deposited in the particle phase.

A similar observation was noted by Clothier (2000) who saw a substantial decrease in transfer from the surface to the hands 24 hours after pesticide application. Although air samples were not taken during the study, Clothier postulated the decrease in surface transfer resulted not from loss through volatilization because the test substances were semi-volatiles but because of increased adhesion to the surface. It is unknown whether the pesticide concentration on the test surface increased after approximately 72 hours as observed by Gurunathan because Clothier reapplied pesticides on the third day of the 4-day experiment.

The idea that certain compounds may bind to surfaces creates the potential for exposure from inhalation of these substances as they are released over time. The modeling concept is similar to the migration principle used by the U.S. Food and Drug Administration (USFDA or FDA) to evaluate the diffusion of additives in food packaging material to food items, except in this case the medium of interest is the ambient air not food. However, contribution from this exposure pathway is expected to be insignificant when compared to direct contact with contaminated surfaces. As mentioned in the previous section, Gurunathan and her team concluded exposure via inhalation was negligible, with most of a child's dose coming from direct mouthing contact with contaminated objects. Since that study measured chlorpyrifos concentration by collecting particulate matter less than 10 μm ($\leq PM_{10}$), the amount of chlorpyrifos in the vapor phase is

expected to be even less than the observed concentration. Therefore, although exposure to vapors released from sorptive surfaces is a potential exposure pathway, this TG does not evaluate this pathway when estimating exposures from contact with surface contaminants.

CHAPTER 10
QUANTIFYING INTAKE AND DOSE

This chapter presents the parameters needed to estimate contaminant-specific intake and dermal dose for the office worker scenario. As the three exposure pathways have distinct parameters, each pathway is discussed separately. In addition, since this TG considers only nonrenewable contamination, mass balance is also discussed as it is used to bound the exposure duration.

10.1 Intake Assumptions

Typically, health risk estimates are calculated by assuming a scenario involving exposure to the same contaminant concentration for the entire ED, which is typically 25 years for the office worker scenario. Although this simplifies calculations, this assumption overestimates exposure, especially for substances that have short half-lives. As mentioned in paragraph 8.2, not much is known about degradation of substances indoors. Therefore, this TG does not attempt to account for substance loss via natural degradation. Instead, loss from the surface is estimated by treating every fraction transferred from the surface to the skin (FT_{ss}) as a removal of the same fraction from the surface. Paragraph 10.2.3 provides more discussion on the mass balance analysis. Chapters 4 and 5 further discuss how these intakes and dose are combined with a contaminant's toxicity information (chapter 4) to estimate health risks or to derive health-based screening levels.

10.2 Dermal Absorbed Dose

The dermal absorbed dose (DAD) is the amount of substance absorbed through the skin. As mentioned earlier, since equation is linear, total dermal dose is based on the cumulative number of contacts per day and the length of exposure (years). The equation for estimating DAD is as shown in equation 10-1, and the input parameters are discussed separately below.

Equation 10-1

$$DAD = \frac{PD_{derm} \cdot ABS_d \cdot EV_{derm} \cdot EF \cdot ED \cdot 10^{-3}}{BW \cdot AT}$$

Where:

DAD	=	dermal absorbed dose (mg/kg/day)
PD_{derm}	=	potential dermal dose (µg/event)
ABS_d	=	dermal absorption fraction (unitless)
EV_{derm}	=	event frequency for estimating the dermal dose (events/day)
EF	=	exposure frequency (days/year)
ED	=	exposure duration (year)
10^{-3}	=	units conversion factor (µg to mg)
BW	=	body weight (kg)
AT	=	averaging time (days)

10.2.1 Potential Dermal Dose (PD_{derm})

The potential dermal dose is a calculated parameter and is discussed in paragraph 9.2.1.

10.2.2. Dermal Absorption Fraction (ABS_d)

10.2.2.1 Dermal Absorption Factors

The dermal absorption fraction is a substance-specific parameter that is used to estimate how much of the substance deposited on the skin is absorbed through the skin. The ABS_d is affected by various factors such as particle size and organic carbon content as well as the substance's physical-chemical properties (USEPA 1992b; Reifenrath et al. 2002). Reifenrath et al. (2002) reported observing reduced absorption in pigskin when organic matter was added to low-carbon soil. In another experiment, the authors found pesticide and PAH concentrations in house dust increased with decreasing particle size (Lewis et al. 1999). The authors concluded the inverse relationship shows these compounds are mostly adsorbed to the surface of dust particles, not absorbed into the particles. This suggests skin absorption in smaller particles is higher than large particles because of the greater surface-to-volume ratio in smaller particles.

Currently, there are no dermal absorption fractions developed specifically for substances adsorbed to indoor particles. Therefore, dermal absorption fractions based on skin absorption of substances bound in soil (or other outdoor particles) are used in this TG. The USACHPPM has developed a document that provides a standard procedure for selecting dermal absorption fractions (USACHPPM 2007). This document provides the steps for selecting dermal absorption fractions, which includes substance-specific values recommended by the USEPA (2004b) as well as values for CWAs developed by USACHPPM (1999b). Unlike USEPA recommendations, which were derived from 24-hour experimental studies, absorption fractions for CWAs were approximated using a model initially developed for estimating dermal absorption of drugs

(USACHPPM 1999b; Fiserova-Bergerova et al. 1990). Dermal absorption fractions for CWAs are expressed as an absorption rate (fraction per hour), which must be adjusted for event duration. The event duration in this case estimates the length of time substance on the skin is available for absorption. Mathematically, the maximum event duration should not exceed 1 day (24 hours) because exposures greater than 1 day are accounted for by the EF in equation 10-1. It should be noted that although USEPA-recommended ABS_d values were derived from 24-hour studies, the USEPA (2004b) states they should not be adjusted for time. Instead, site-specific conditions should be accounted for by adjusting the EF and ED (USEPA 2004b).

To be consistent with USEPA-recommended ABS_d values, hourly absorption rates for CWAs were multiplied by 24 hours to obtain ABS_d for 24-hour events. Recall from paragraph 9.2.1.1 that the exposed skin area for the office worker scenario includes forearms. While hand washing may be more frequent, washing the forearms is not. Therefore, assuming substances could remain on the skin for 24 hours is not unreasonable because an informal survey of office workers (n = 26) shows roughly half have a habit of showering/bathing in the mornings. This means substances (bound or unbound to indoor particle) that adhered to the skin may not be washed off until the next day.

As shown in table 10-1, substance-specific ABS_d values are few. The USEPA suggests a default ABS_d of 10 percent (0.1) for SVOCs when no substance-specific values are available, but recommends against default ABS_d values for inorganics or VOCs (USEPA 2004b). The USEPA rationale is that VOCs should be accounted for via the inhalation route of exposure. As for inorganics, the agency reasons that compound speciation is an important consideration, and currently there is too little data to extrapolate a "reasonable default value."

When no ABS_d values are available, potential health risks from direct dermal contact cannot be evaluated. This data gap could be problematic because, for exposure to surface contaminants, direct dermal contact is a significant exposure pathway. While not an issue for VOCs because this TG does not recommend wipe sampling of VOCs, metals are commonly sampled for via wipe sampling. Wipe sample results for metals are usually not speciated.

The USEPA Region 3 uses a default ABS_d of 1 percent (0.01) to develop risk-based soil screening levels for metals with no chemical-specific ABS_d values (USEPA 2003e). This default was previously recommended by the USEPA before the agency revised its dermal risk assessment guidance. In order to derive health-based screening levels for this TG, a default ABS_d of 1 percent (0.01) is also recommended for metals with no chemical-specific ABS_d. Dermal absorption of metals is thought to be low, and a default of 0.1 percent (0.001) has been

used to evaluate skin absorption of metals from textiles (Danish Environmental Protection Agency (DEPA) 2003). Therefore, a default value of 1 percent is expected to provide protective health risk estimates.

Table 10-1 summarizes all ABS_d values recommended for this TG. For dioxins, the USEPA lists two different fractions based on the soil's organic carbon content: 0.001 if organic content is > 10 percent, 0.03 if organic content is ≤ 10 percent. Studies consistently show that organic matter in indoor dust/particles is higher than outdoor soil/particles. Rasmussen (2004) estimated an organic carbon content ranging from 20-34 percent in house dust while Mølhave et al. (2000) estimated office dust contained about 33 percent organic matter. Based on these observations, the lower ABS_d of 0.001 is recommended for TCDD and other dioxins.

Table 10-1. Dermal Absorption Fractions (ABS_d)

Substance	ABS_d	Substance	ABS_d
Arsenic	0.03	2-Amino-4,6-Dinitrotoluene	0.006
Cadmium	0.001	4-Amino-2,6-Dinitrotoluene	0.009
Chlordane	0.04	2,4-Diamino-6-nitrotoluene	0.011
2,4-Dichlorophenoxyacetic acid	0.05	2,6-Diamino-4-nitrotoluene	0.005
DDT	0.03	Trinitrotoluene (TNT)	0.032
TCDD and other dioxins	0.001[a]	Octahydro-1,3,5,7-tetranito-1,3,5,7-tetrazocine (HMX)	0.006
Lindane	0.04	N-methyl-N, 2,4,6-tetranitrobenzamine (tetryl)	0.00065
Benzo(a)pyrene and other PAHs	0.13	GB[b]	0.084
Aroclors 1254 and 1242, other PCBs	0.14	Tabun (GA[b])	0.0624
Pentachlorophenol	0.25	Soman (GD[b])	0.187
Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)	0.015	VX[b]	0.065
Thiodiglycol	0.0075	HD[b]	0.168
Trinitrobenzene	0.019	Default ABS_d	
2,4-Dinitrotoluene (2,4-DNT)	0.102	SVOCs	0.1
2,6-Dinitrotoluene (2,6-DNT)	0.099	Metals	0.01[c]

[a]For organic carbon content >10%
[b]ABS_d estimated from hourly absorption rate multiplied by 24 hours
[c]USEPA (2004b) does not recommend a default ABS_d for metals.

10.2.2.2 Uncertainties and Limitations

The following uncertainties and limitations apply to the dermal absorption fractions recommended in table 10-1.

• Substance-specific dermal absorption fractions were estimated from experimental studies involving spiked soils. As discussed in the text, indoor particles typically have higher organic

carbon content than outdoor particles. This reduces bioavailability of substances bound to the indoor particles, resulting in lower dermal absorption fractions when compared to soil particles with lower organic carbon content.

• While soil ABS_d may overestimate skin absorption for substances absorbed/adsorbed to particles with high organic matter, the opposite is probably true when used to estimate film-type contaminants. For this type of surface contamination, permeability constants similar to those used for estimating dermal absorption from contact with substance in aqueous solution may be more appropriate. However, very few permeability constants for "neat" agents are currently available.

• Dermal absorption fractions for CWAs were not derived from experimental studies but estimated using assumptions based on soil properties. For example, USACHPPM (1999b) relied on the soil pore-water property to estimate bioavailability of CWA not bound to the organic carbon content of a soil particle. A 2-percent organic carbon content was used, which would result in more CWA available for dermal absorption because of the higher organic carbon content in indoor particles. However, indoor particles do not exist in a pore-water matrix. The effect of this assumption on the ABS_d is unknown.

• Equation 10-1 assumes all substances adhered to the skin remain on the skin for 24 hours and are available for absorption during this period. Realistically, substance skin loading is significantly reduced over the 24-hour period because, if the substance is not washed off, some of the substance will be rubbed off the exposed skin. In addition, some have postulated that absorption occurs only for a single layer of particles (see USEPA 1992b). However, uncertainties associated with the monolayer concept may be reduced by selecting ABS_d values estimated from particles of similar size.

• Although the USEPA does not recommend a default ABS_d for metals, this TG provides a default ABS_d for the purposes of developing screening levels. Compound-specific ABS_d for metals should be used for site-specific assessments.

• In addition to the substance's physicochemical characteristics, the amount of substance absorbed through the skin depends on factors such as the anatomical site of exposure or age of the skin (USEPA 1992b). Experimental studies have shown increased absorption with decreased thickness in stratum corneum (USEPA 1992b). For example, one study showed absorption of parathion applied to the forehead was three times higher than the fraction absorbed when applied to the palm area; the stratum corneum thickness in the palm area is about 30 times greater than that of the forehead (USEPA 1992b). In addition, the skin may be vulnerable (for example, genetic susceptibility) or damaged (for example, sunburn), increasing the fraction absorbed.

10.2.3 Exposure Duration (ED)

10.2.3.1 Exposure Duration Factors

Exposure duration estimates the length of time exposure to indoor surface contaminants may occur. For workers, ED is usually determined by estimating how long workers may be employed at the same location (USEPA 1991). According to 2006 Bureau of Labor Statistics (BLS) data, the median number of years employees had been with the same employer was only 4 years. Data suggest factors such as age, industry, and occupation affect employee tenure (BLS 2006a). The median tenure of workers age 55 to 64 years was 9.3 years compared to 2.9 years for those age 25 to 34 years (BLS 2006a).

For estimating worker exposure, the USEPA (1991) recommends using a 95th percentile ED of 25 years, which is based on 1990 BLS data. This ensures results reflect reasonable maximum exposures (RMEs) that provide conservative, yet reasonable estimates (USEPA 1989b). However, as shown below, since this TG considers only nonrenewable contamination, assuming an ED of 25 years overestimates potential health risks because substances on the surface are lost over time and not replenished (although they could be redistributed).

10.2.3.1.1 Mass balance considerations

Mass balance considerations were not carried out by modifying existing equations. Rather, an analysis was performed to estimate how long it would take to deplete contaminants from a surface when skin contact was the only loss mechanism. Although substances on the surface may be transported or transferred to another medium (for example, desktop or bag placed on the desk), these transfer mechanisms were ignored to provide conservative estimates. Using these assumptions, substance loss from the surface may be estimated as follows:

Equation 10-2

$$C_{ED} = \left(C_s \cdot A_{cs}\right) \cdot e^{-k \cdot ED}$$

Where:

C_{ED} = total contaminant mass at the end of the exposure duration (µg)
C_s = contaminant surface loading (µg/m^2)
A_{cs} = contact surface area (m^2)
k = loss based on fraction transferred from the surface to the skin (1/yr)
ED = exposure duration (yr)

The loss constant, k, is based on the fraction transferred to the skin (FT_{ss}), number of contact events per day (EV_{derm}), and the number of days spent in the office per year (EF). Both EV_{derm} and EF were set lower than the default values recommended in this TG to slow the rate of depletion (table 10-2). The EF of 220 days/year comes from the assumptions of Michaud et al. (1994) and accounts for holidays, sick days, and vacation. Different contact surface areas (A_{cs}) were used to ensure that the estimated time (ED) for substances to deplete from the surface would not be underestimated. An A_{cs} of 400 ft^2 is the office space typically assigned to upper management (see paragraph 9.2.3.5). A surface area of 465 m^2 was also used to assess how long it would take for substances to deplete from an area this large. This value is based on data compiled in the 2003 Commercial Building Energy Consumption Survey (CBECS), which showed most of the offices surveyed (>75 percent) were smaller than 5,000 ft^2 (465 m^2) (EIA 2006b). Assuming the same person would come in direct contact with the entire office space, an area this large is unrealistic as the most likely contact surfaces are probably limited to each worker's immediate workspace and communal areas (for example, lunch room, conference room).

Mass balance analysis was conducted by inserting an initial surface loading into equation 10-2 and observing how many years it would take for the surface loading to be significantly reduced (C_{ED}). Actual wipe sampling results from several studies were reviewed, and the highest surface loading detected from these studies was selected for the mass balance analysis. Data reviewed included wipe sample results reported in NIOSH health hazard evaluations, USACHPPM studies, and results from the World Trade Center Residential Dust Cleanup Program. The highest surface loading of 30 million $\mu g/m^2$ was reported for a wipe sample taken from "grossly contaminated surfaces" when a transformer overheated and released PCBs indoors (CDC 1985). Table 10-2 summarizes parameters and input values used in the mass balance analysis.

Table 10-2. Parameters and Values Used to Assess Mass Balance

Parameter	Definition	Value
C_s	Contaminant surface loading	3×10^{-7} $\mu g/m^2$ (300,000 $\mu g/100\ cm^2$)
A_s	Contact surface area	Range: 37 to 465 m^2 (400 to 5,000 ft^2)
k	Loss of substance from the surface	$FT_{ss} \times EV_{derm} \times EF = 2.2\ yr^{-1}$
ED	Exposure duration	Range: 0 to 70 years
FT_{ss}	Fraction transferred from surface to the skin	1% (0.01)[a]
EV_{derm}	Dermal exposure event frequency	1 event per day[a]
EF	Exposure frequency	220 days per year[a]

Note:
[a]Different from defaults recommended in this TG. Lower values were used to slow the rate of depletion for mass balance analysis. If recommended defaults are used, $k = 66\ yr^{-1}$.

Remaining surface loadings at the end of each year were calculated for up to 70 years, which was not necessary because substance loading reduced significantly within the first few years. Even at artificially low contact rates, surface loading reduced by an order of magnitude every year. For a 37 m^2 contact surface area, total mass went from 1.1 x 10^{-9} µg to 1.9 x 10^{-4} µg at the end of the fifth year (see table 10-3). Increasing EV_{derm} from 1 to 2 events per day further reduced the total mass to 0.31 µg at the end of year 5. When viewed alone, however, surface loads do not provide insight to potential health risks. Therefore, health risk estimates were calculated to determine whether exposure to the remaining surface load would pose significant health risks. Except for assuming an ED of 25 years, default values recommended in this TG, as opposed to the test values listed in table 10-2, were used to calculate conservative health risk estimates. Had these default values been used to calculate changes in surface loading over time, C_s would have depleted at an even faster rate.

Additional levels of conservatism were incorporated by selecting a high dermal absorption factor of 0.25 for pentachlorophenol and a low noncancer toxicity value of 0.00002 mg/kg/day for Aroclor 1254. However, the cancer toxicity value of 2,3,7,8-TCDD was not used even though it would provide the most conservative estimates for carcinogenic effects, because a review of wipe sampling data shows dioxin/furan results are typically low compared to other substances. Hence surface loadings are usually reported in nanograms and not micrograms. The mass balance analysis would not be very useful if dioxins/furans are not expected to be detected at loadings of up to 30 million µg/m^2. Therefore, the upper bound slope factor of PCB (2 per mg/kg/day) was used to evaluate carcinogenic effects. Specific equations and other parameters used are not discussed because this section focuses on providing general estimates to support the mass balance analysis. Risk assessors should refer to chapter 6 for discussions on how to calculate noncancer and carcinogenic health risks.

Table 10-3 presents general health risk estimates calculated using the above assumptions. The acceptable limit for noncancer effects is typically 1 while that for cancer effects range from 10^{-4} to 10^{-6}. Results show that if office workers were exposed to a surface load of 0.31 µg (end of year 10) for 25 years, health risk estimates would be well below the acceptable limits for both noncancer and cancer effects. It is interesting to note that even though total mass remaining on the surface for A_s = 465 m^2 was higher than the mass remaining for A_s = 37 m^2, health risk estimates for either scenario were the same because total mass was assumed to be evenly distributed over the contact surface area, resulting in the same surface loading.

Table 10-3. Remaining Surface Loads and Estimated Health Risks

Exposure Duration	Total Mass Remaining at the End of the Exposure Duration (C_{ED})[a] (µg)		Health Risk Estimates: Exposure to C_{ED} for 25 yrs [b] (Direct Skin Contact + Incidental Ingestion)	
Year	**A_s = 465 m^2**	**A_s = 37 m^2**	**Noncancer**	**Cancer**
0	1.4×10^{-10}	1.1×10^{-9}	1.2×10^{-6}	20
5	2.3×10^{-5}	1.9×10^{-4}	20	3×10^{-4}
10	3.8	3.1×10^{-1}	3.3×10^{-4}	5×10^{-9}
15	6.5×10^{-5}	5.2×10^{-6}	5.4×10^{-9}	8×10^{-14}

Notes:
[a] See table 10-2 for parameters used to estimate C_{ED}.
[b] See table 6-1 for parameters used to calculate noncancer and cancer health risk estimates.

10.2.3.1.2 Selection of exposure duration for office workers

As shown in the mass balance analysis, even when using very low contact rates, total mass on the surface depletes significantly every year. At the end of year 10, remaining mass was only a fraction of the original surface load. Therefore, to assume office workers would be exposed to the initial surface load for 25 years not only overestimates exposure but is unrealistic. In addition to the conservative assumptions used to calculate C_{ED} and health risk estimates, particle resuspension and potential removal by filtration mechanisms were ignored in the mass balance assessment. Therefore, actual values are expected to be much lower than those presented in table 10-3. Based on the mass balance analysis, an ED of 10 years is recommended for evaluating office worker exposures.

10.2.3.2 Uncertainties and Limitations

The parameter ED is rather straightforward. However, here are some uncertainties and limitations associated with the recommended default ED:

• The default ED was selected based on the consideration that contaminants are nonrenewable. If a continuous source of contamination is present, the USEPA default of 25 years may be more applicable. The risk assessor should also consider whether site-specific information is available.

• The mass balance analysis uses an initial surface loading of 3×10^{-7} µg/m^2 which was the highest level found after reviewing several different studies. If the surface loading of a single substance or summation of different substances exceeds this level, the risk assessor should consider whether an ED of 10 years is still a reasonable assumption.

10.2.4 Event Frequency for Estimating the Dermal Dose (EV_{derm})

10.2.4.1 Event Frequency Factors

To calculate the daily dermal dose, the potential dose must be multiplied by the number of contact events per day (EV_{derm}). Little office-specific data makes estimating this parameter difficult even after grouping contacts into events as opposed to individual contacts. Past evaluations have relied solely on professional judgment. For example, Michaud et al. (1994) assumed 8 events per day, but the authors focused on maintenance workers exposed only while performing repair or maintenance activities. Similarly, using professional judgment, USEPA Region 3 (Parsons Engineering Science, Inc. 1997) estimated a low-end surface contact rate of 1/day and a worst-case exposure of up to 3/hour (24/day) for workers. However, contact surfaces for which these assumptions were made were limited to floors and walls.

To estimate EV_{derm}, it is necessary to consider contact with a surface that could provide a long-term contaminant source. Although working in front of the computer probably comprises the majority of activities in modern offices, the contact area is generally limited in size for this activity. As discussed in paragraph 10.2.3, surface contaminants deplete much more rapidly with increased contact frequency, shortening the exposure duration. Using the highest detected surface loading as described in paragraph 10.2.3, contaminants on a surface roughly the size of a keyboard (about 0.9 ft^2) would be significantly depleted within 1 year, especially with increased contact frequency. Therefore, selection of EV_{derm} for long-term exposures should attempt to balance out these considerations. This could be done by considering contacts not only with the area immediately in front of the computer but also peripheral surfaces where contacts may be less frequent.

To make the number of office events more manageable, an event is considered to be an uninterrupted activity that involves contact with the contaminated surface. Some examples are computer work (includes typing, working in front of the computer); talking on the phone; and working at a desk away from the computer (for example, writing, reading, attending meetings). When a break occurs, an activity is considered a new event even when the office worker resumes the same activity. Combining this definition with the concept presented in the above paragraph, EV_{derm} could be estimated by time-averaging between the most frequent contact surfaces and infrequent contact surfaces. Most frequent contact surfaces are phone and keyboard areas where contaminants, even at high surface loadings, are expected to be depleted within a year because of the small surface areas. To estimate EV_{derm} for exposures from contact with these surfaces, office workers were assumed to have two activity interruptions every hour to increase the number of events (three events per hour). For an 8-hour workday, EV_{derm} becomes 24 events per day.

After contaminants on frequent-contact surfaces have been depleted (1 year), remaining exposures come from contacts with peripheral surfaces. This distinction is made only to simplify assumptions. In reality, skin contact with infrequently contacted surfaces could also occur during the first year. For this TG, EV_{derm} for contact with peripherally contaminated surfaces was assumed to occur twice a day (two events per day). This value is based on professional judgment on how often office workers may conduct non-computer-related activities. If the entire exposure duration is 10 years, a time-averaged EV_{derm} could be calculated as follows in equation 10-3:

Equation 10-3

$$EV_{avg} = \frac{(24\ events\ per\ day)(1\ year) + (2\ events\ per\ day)(9\ years)}{10\ years} = 4.2\ events/day$$

Where:

EV_{avg} = average event frequency

For this TG, an EV_{derm} of four events per day is recommended for estimating office worker exposures from skin contact with contaminated, smooth surfaces.

10.2.4.2 Uncertainties and Limitations

The risk assessor should consider the following uncertainties and limitations:

• The recommended EV_{derm} was selected using professional judgment; long-term exposures; smooth, nonporous surfaces; and nonrenewable contaminant sources. The default value should not be used for exposure scenarios that are significantly different from these considerations.

• No office-specific data were available so EV_{derm} was estimated using professional judgment. If office activity-specific data become available, EV_{derm} should be reevaluated using actual data. In addition, since EV_{derm} is currently time-weighted over office workers' ED, when the exposure duration changes, EV_{derm} should also be readjusted.

10.2.5 Exposure Frequency (EF)

10.2.5.1 Exposure Frequency Factors

Exposure frequency is used to estimate the number of days exposure occurs in the workplace. The USEPA typically uses a default EF of 250 days per year for occupational exposures (USEPA 1991). This value assumes workers spend 5 days/week at the same location and is consistent with the BLS 2006 American Time Use Survey, which showed workers spent an average of 39.2 hours per week at work. When broken down by profession, workers in "management, business, and financial operations" worked slightly more hours—43.4 hours/week compared to 37.5 hours for sales and office/administrative support workers (BLS 2006b). The value of 250 days per year also includes 2 weeks leave taken through the year. Michaud et al. (1994) assumed 220 days per year to account for holidays and sick days as well. For this TG, a default EF of 250 days per year, consistent with USEPA recommendations, is used.

10.2.5.2 Uncertainties and Limitations

Unless site-specific information shows workers' schedules differ significantly from the default EF of 250 days/year, the default EF provided in this TG is rather straightforward.

10.2.6 Body Weight

10.2.6.1 Body Weight Factors

Total dose or intake is usually normalized to body weight. The USEPA (1989b) recommends an average body weight be used to estimate RMEs and to avoid potential inconsistencies when combined with other input parameters. As an example, combining 95th percentile intake rates with 5th percentile body weight is not reasonable because of the unlikely event that the smallest person would have the highest intakes (USEPA 1989b). Similarly, as applied to dermal exposures, body weight should be correlated with the skin surface area (see paragraph 9.2.1.1) used to estimate the dermal dose.

An adult body weight of 70 kg is still commonly used to assess human health risks even though data show body weight of the U.S. population has increased steadily over the years (USEPA 1997b; Ogden et al. 2004). The mean adult body weight of 71.8 kg listed in the 1997 Exposure Factors Handbook is probably even higher now because that body weight was estimated from 1987 data. Ogden et al. (2004) estimated adults gained an average of 24 pounds (about 11 kg) between 1960 and 2002. Although the USEPA recommends using data most representative of the exposed population, the agency also cautions this could result in inconsistencies with the way

the agency derives CSFs and URs where a body weight of 70 kg is still used (USEPA 1997b). Therefore, this TG recommends a default body weight of 70 kg to evaluate potential health risks to office workers. Since dose or intake is calculated by dividing the potential dose by the body weight, a lower body weight results in a higher dose or intake, resulting in more health-protective estimates.

10.2.6.2 Uncertainties and Limitations

Body weight data is readily available so there is little uncertainty associated with the recommended default. However, if the risk assessor determines a different body weight is more applicable, for example, to evaluate health risks to a specific population, the risk assessor should consider whether dose response information needs to be adjusted, or at least discuss potential inconsistencies.

10.2.7 Averaging Time (AT)

10.2.7.1 Time Factors

Two different averaging times are used depending on the toxicity endpoint being evaluated. For noncancer health effects, dose or intake is normally averaged over the ED. However, for carcinogens, the total cumulative dose or intake is averaged over a lifetime because of the assumption that no dose, no matter how small, is considered "risk-free" (USEPA 1989b).

The USEPA (1997b) recommends a life expectancy of 75 years, but recent data suggests the average life expectancy is closer to 77.8 years, up 0.4 from 77.4 years estimated from 2003 statistics (Arias 2006; Miniño et al. 2007). Despite the increase in life expectancy, a lifetime of 70 years is still commonly used to assess human health risks. Like the reasons for selecting an outdated body weight, until the USEPA changes its method of deriving CSFs and URs, this TG recommends a lifetime of 70 years for evaluating carcinogenic effects. For assessing noncancer health effects, the default ED of 10 years, as recommended in paragraph 10.2.3, is used. Since averaging time is expressed in days, averaging times for evaluating noncancer and carcinogenic health effects are 3,650 days and 25,550 days, respectively.

10.2.7.2 Uncertainties and Limitations

The averaging time is a fairly straightforward parameter. However, statistics show life expectancy changes when the population is broken down by gender and race (Arias 2006; Miniño et al. 2007). Therefore, the risk assessor should consider whether a different life expectancy should be used to evaluate carcinogenic health effects. If so, as noted in the body weight

discussion, the risk assessor should determine whether dose response information needs to be adjusted, or at least discuss potential inconsistencies.

10.3 Intake from Incidental Ingestion

Average daily intake from incidental ingestion of surface contaminants transferred to the hands and then to the mouth via mouthing behavior is estimated as follows:

Equation 10-4

$$ADI_{ing} = \frac{PD_{ing} \cdot EV_{ing} \cdot EF \cdot ED \cdot 10^{-3}}{BW \cdot AT}$$

Where:

ADI_{ing} = average daily intake from incidental ingestion (mg/kg/day)
PD_{ing} = potential dose from incidental ingestion (µg/event)
EV_{ing} = event frequency for estimating intake from incidental ingestion (events/day)
EF = exposure frequency (days/year)
ED = exposure duration (year)
10^{-3} = units conversion factor (µg to mg)
BW = body weight (kg)
AT = averaging time (days)

The ingested dose is often assumed to be 100 percent absorbed by the gastrointestinal tract, which is the portal-of-entry for ingested substances; therefore, an absorption factor similar to the one used to estimate a dermal dose is usually omitted.

10.3.1 Potential Dose from Incidental Ingestion (PD_{ing})

The potential ingested dose is calculated using either equation 9-2 or equation 9-3 depending on the exposure activity.

10.3.2 Event Frequency for Estimating Intake from Incidental Ingestion (EV_{ing})

10.3.2.1 Event Frequency Factors

To calculate an average daily intake from incidental ingestion of surface contaminants, it is necessary to estimate the number of hand-to-mouth contacts for each activity. As discussed in

paragraph 9.2.2, this TG focuses on three different, yet likely activities from which office workers could be exposed via incidental ingestion: fingernail biting, eating a food item such as a sandwich, and cigarette smoking. Although exposure from eating a sandwich may be greater than smoking a cigarette, when each activity is considered in conjunction with the daily event frequency, the average daily intake from smoking may be higher. Estimation of the EV_{ing} for each activity is described below.

10.3.2.1.1 Estimating event frequency for fingertip/fingernail biting habits

The majority of data on hand-to-mouth frequency published to date has focused on young children because of their much higher exposure level from this activity when compared to adults. One study did look at the factors that could influence worker exposure from incidental ingestion (Zainudin and Semple 2005). Observing 64 workers from three different work environments (laboratory, manufacturing/engineering, and office), Zainudin and Semple (2005) noted that the number of hand-to-face contacts decreased if the worker's job function involved a high level of hand activity. This suggests that the number of hand-to-mouth contacts among workers could be tied to a job function. The authors did not observe any nail biters but reported office workers had the highest number of hand contacts with the area around the mouth ("peri-oral"), averaging 3.4 contacts per hour compared to 1.8 contacts per hour for manufacturing/engineering workers and 0 (zero) contacts per hour for laboratory workers.

For the purposes of estimating office worker exposure from incidental ingestion, Zainudin's observation of 3.4 hand-to-perioral area contacts per hour was used to estimate EV_{ing} for fingertip/fingernail biting habits. Multiplying this by a typical 8-hour workday results in a total EV_{ing} of 27 events/day.

10.3.2.1.2 Estimating event frequency for ingested "items"

To simplify assumptions, this TG focuses on a sandwich or other similar food items to evaluate incidental ingestion of surface contaminants from ingestion of hand-held food items (see paragraph 9.2.2.7). This TG assumes an EV_{ing} of two events/day (that is, two sandwiches during an 8-hour workday) for estimating exposures from this activity.

10.3.2.1.3 Estimating event frequency for cigarette smoking

For this TG, smokers were assumed to smoke once every hour during an 8-hour office workday. This results in a total EV_{ing} of 8 events/day. Table 10-4 summarizes the event frequencies for estimating exposures from incidental ingestion in the workplace.

Table 10-4. Recommended Event Frequencies for Different Workplace Activities/ Behaviors

Workplace Activity/Worker Behavior	Recommended Value[a] (Events/Day)
Fingertip/fingernail biting habit	27
Eating food items such as a sandwich or hamburger	2
Smoking	8
[a]Assumes an 8-hour workday	

10.3.2.2 Uncertainties and Limitations

The risk assessor should consider the following uncertainties and limitations:

• Recommended EV_{ing} values were estimated by assuming a typical workday of 8 hours. A change in the worker's daily shift (for example, 10 hours/day) will not impact the average daily intake if the worker works a 40-hour workweek (see also discussion on exposure frequency, paragraph 10.3.3). If the risk assessor wants to modify EV_{ing} to account for a longer or shorter workday, the risk assessor should also consider whether the exposure frequency needs to be modified as well.

• Zainudin and Semple (2005) observed hand-to-face contact frequency is affected by the worker's job function, personal behavior (for example, smoking), and what the authors termed presence of "office furniture" on the face (for example, eye glasses, facial hair). These factors indicate EV_{ing} is a highly variable parameter, and a single value is not recommended for different activities. The values recommended in this TG are intended to provide conservative estimates without overestimating exposure. Risk assessors could consider modifying the assumptions used based on site-specific information. For example, if the risk assessor has better information to estimate fingertip biting habits, the risk assessor could consider whether to modify EV_{ing} for this activity.

10.3.3 Exposure Frequency (EF)

The parameter EF is discussed in paragraph 10.2.5, and a default value of 250 days per year is recommended for this TG.

10.3.4 Exposure Duration (ED)

Exposure duration is discussed in paragraph 10.2.3. This TG recommends a default ED of 10 years, which is capped by mass balance considerations.

10.3.5 Body Weight

As discussed in paragraph 10.2.6, this TG recommends a default adult body weight of 70 kg for evaluating office worker exposures.

10.3.6 Averaging Time (AT)

Paragraph 10.2.7 presents a discussion of the parameter averaging time and recommends default values of 3,650 days and 25,550 days for estimating noncancer and cancer exposures, respectively.

10.4 Intake from Inhalation of Resuspended Particles

The equation for estimating the average daily intake from inhalation is as shown in equation 10-5 and each input parameter is discussed separately below.

Equation 10-5

$$ADI_{inh} = \frac{C_{air} \cdot IR_{inh} \cdot ET \cdot EF \cdot ED \cdot 10^{-3}}{BW \cdot AT}$$

Where:

ADI_{inh} = average daily intake from inhalation (mg/kg/day)
C_{air} = resuspended air concentration (µg/m^3)
IR_{inh} = inhalation rate (m^3/hr)
10^{-3} = units conversion factor (µg to mg)
ET = exposure time (hours/day)
EF = exposure frequency (days/year)
ED = exposure duration (year)
BW = body weight (kg)
AT = averaging time (days)

The inhaled dose is often assumed to be 100 percent absorbed by the lungs, which is the portal-of-entry for inhaled substances; therefore, an absorption factor similar to the one used to estimate a dermal dose is usually omitted.

10.4.1 Resuspended Air Concentration

The resuspended air concentration (C_{air}) is a calculated parameter and is discussed in paragraph 9.2.2.

10.4.2 Inhalation Rate (IR_{inh})

Inhalation rate (IR_{inh}) is used to estimate the amount of substance inhaled during the exposure period. Values of IR_{inh} vary depending on activity intensity, age, gender, and level of fitness. The USEPA recommends default values of 20 m^3/day (0.833 m^3/hr) for evaluating inhalation hazards.

10.4.3 Exposure Time (ET)

10.4.3.1 Exposure Time Factors

Exposure time is used to estimate how long office workers will be exposed during the day and depends on both the exposure pathway and exposure scenario. For workers, this is usually estimated by determining the number of hours workers spend working in a contaminated environment. A default 8-hour workday is typically used to assess workplace exposures (see, for example, Michaud et al. 1994). This is consistent with a recent BLS survey which showed workers worked an average of 7.6 hours per day (BLS 2007). When data was broken down between weekdays and weekends, workers spent more hours on weekdays, working 8.0 hours compared to 5.4 hours for those who worked on weekends (BLS 2007). Based on recent BLS data, a default ET of 8 hours per day is recommended for this TG.

10.4.3.2 Uncertainties and Limitations

The parameter ET is fairly straightforward. However, risk assessors should consider the following limitations and decide whether a different ET may be more appropriate for their assessment.

- The default ET assumes office workers spend 8 hours per day in the same environment and may overestimate exposure for workers who spend a large part of their workday away from the contaminated area.

• Using a default ET of 8 hours a day assumes office workers are exposed to the same resuspended air concentration for 8 hours every day. Since the resuspended air concentration depends on the degree and frequency of disturbance activities, the total inhalation intake at the end of each day may be overestimated or underestimated when using this assumption.

• Given today's changing work environment, some workers may have a schedule different from the traditional 8-hour workday. For example, some workers may work 10 hours a day, but only 4 days a week. As long as the total number of hours worked per week is 40, risk assessors need not adjust the ET or the EF, which is discussed next.

10.4.4 Exposure Frequency (EF)

The parameter EF is discussed in paragraph 10.2.5, and a default value of 250 days per year is recommended for this TG.

10.4.5 Exposure Duration (ED)

Exposure duration is discussed in paragraph 10.2.3. This TG recommends a default ED of 10 years, which is capped by mass balance considerations.

10.4.6 Body Weight

As discussed in paragraph 10.2.6, this TG recommends a default adult body weight of 70 kg for evaluating office worker exposures.

10.4.7 Averaging Time (AT)

Paragraph 10.2.7 presents a discussion of the parameter averaging time and recommends default values of 3,650 days and 25,550 days for estimating noncancer and cancer exposures, respectively.

APPENDIX A
REFERENCES

Following is a list of references cited within this TG. For some references, Web sites are provided. Contact USACHPPM in regard to availability of those references for which a Web site is not provided.

Abt, E., H.H. Suh, G. Allen, and P. Koutrakis. 2000a. Characterization of indoor particle sources: A study conducted in the metropolitan Boston area. *Environmental Health Perspectives* 108(1):35-44

Abt, E., H.H. Suh, P. Catalano, and P. Koutrakis. 2000b. Relative contribution of outdoor and indoor particle sources to indoor concentrations. *Environmental Science and Technology* 34(17):3579-3587.

Abu-Eid, R.M., R.B. Codell, N.A. Eisenberg, T.E. Harris, and S. McGuire. 2002. NUREG-1720. Re-evaluation of the Indoor Resuspension Factor for the Screening Analysis of the Building Occupancy Scenario for NRC's License Termination Rule. Draft Report for Comment. Washington, D.C.: U.S. Nuclear Regulatory Commission.

American Conference of Governmental Industrial Hygienists. 2007. *2007 TLVs® and BEIs®, Threshold Limit Values for Chemical Substances and Physical Agents, Biological Exposure Indices*. Cincinnati, OH: ACGIH®.

Arias, E. 2006. United States Life Tables, 2003. *National Vital Statistics Reports* 54:14.

ASTM International. 2003a. ASTM E1728-03. *Standard Practice for Collection of Settled Dust Samples Using Wipe Sampling Methods for Subsequent Lead Determination.* West Conshohocken, PA: ASTM International (Committee E06.23 on Lead Hazards Associated with Buildings). Available from http://www.astm.org/Standards/E1728.htm.

ASTM International. 2003b. ASTM E1792-03. *Standard Specification for Wipe Sampling Materials for Lead in Surface Dust*. West Conshohocken, PA: ASTM International (Committee E06.23 on Lead Hazards Associated with Buildings). Available from http://www.astm.org/Standards/E1792.htm.

ASTM International. 2006a. ASTM D6661-01(2006). *Standard Practice for Field Collection of Organic Compounds from Surfaces Using Wipe Sampling*. West Conshohocken, PA: ASTM International (Committee D34.01.02 on Sampling Techniques). Available from http://www.astm.org/Standards/D6661.htm.

ASTM International. 2006b. ASTM D7296-06. *Standard Practice for Collection of Settled Dust Samples Using Dry Wipe Sampling Methods for Subsequent Determination of Beryllium and Compounds*. West Conshohocken, PA: ASTM International (Committee D22.04 on Workplace Air Quality). Available from http://www.astm.org/Standards/D7296.htm.

ASTM International. 2008. ASTM D6966-08. *Standard Practice for Collection of Settled Dust Samples Using Wipe Sampling Methods for Subsequent Determination of Metals*. West Conshohocken, PA: ASTM International (Committee D22.04 on Workplace Air Quality). Available from http://www.astm.org/Standards/D6966.htm.

Bahnfleth, W.P., J.D. Freihaut, and P. Aumpansub. 2007. *Phase III Task 7 Report: Implementation of Re-suspension Factors in Building Air Flow Simulations for Cross Contamination Risk Assessment in Multi-Zone Buildings and Determination of Source Strengths Associated with Given Levels of Risk Reduction*. Contract No. W91ZLK-05-P-0838. Prepared for the U.S. Army Center for Health Promotion and Preventive Medicine, Aberdeen Proving Ground, MD, by Pennsylvania State University, University Park, PA.

Barley, D. 2001. Technical Report No. NREL/TP-550-30107. An Overview of Residential Ventilation Activities in the Building America Program (Phase 1). (Contract No. DE-AC36-99-GO10337.) Golden, CO: National Renewable Energy Laboratory (NREL), U.S. Department of Energy.

Biwer, B.M., S. Kamboj, J. Arnish, C. Yu, and S.Y. Chen. 2002. NUREG/CR-6755, ANL/EAD/TM/02-1. *Technical Basis for Calculating Radiation Doses for the Building Occupancy Scenario Using the Probabilistic RESRAD-BUILD 3.0 Code*. Washington, DC: U.S. Nuclear Regulatory Commission.

BLS. 2006a. USDL 06-1563. *Employee tenure in 2006*. Washington, DC: U.S. Department of Labor, Bureau of Labor Statistics. Available from: http://www.bls.gov/news.release/history/tenure_09082006.txt.

BLS. 2006b. *Labor Force Statistics from the Current Population Survey: Annual Averages–Household Data, Characteristics of the Employed: Persons at work by occupation, sex and usual full- or part-time status.* Washington, DC: U.S. Department of Labor, Bureau of Labor Statistics. http://www.bls.gov/cps/ (accessed November 30, 2007).

BLS. 2007. *American Time Use Survey: Charts by Topic–Work and Employment*. Washington, DC: U.S. Department of Labor, Bureau of Labor Statistics. http://www.bls.gov/tus/charts/work.htm (accessed December 3, 2007).

Boeniger, M.F. 2003. The significance of skin exposure. *Annals of Occupational Hygiene* 47(8):591-593.

Brisson, M.J., A.A. Ekechukwu, K.E. Ashley, and S.D. Jahn. 2006. Opportunities for Standardization of Beryllium Sampling and Analysis. *Journal of ASTM International* 3(1).

Brouwer, D.H., R. Kroese, and J.J. Van Hemmen. 1999. Transfer of contaminants from surface to hands: experimental assessment of linearity of the exposure process, adherence to the skin, and area exposed during fixed pressure and repeated contact with surfaces contaminated with a powder. *Applied Occupational and Environmental Hygiene* 14(4):231-239.

Brunskill, R.T. 1967. The relationship between surface and airborne contamination. In *Surface Contamination*, ed. B.R. Fisher, 93-104. New York: Pergamon Press Ltd.

Butte, W., and B. Heinzow. 2002. Pollutants in house dust as indicators of indoor contamination. *Reviews of Environmental Contamination and Toxicology* 175:1-46.

California Department of Food and Agriculture. 1990. Memorandum from Michael Dong, Staff Toxicologist, to John Ross, Senior Toxicologist, 8 June 1990, subject: Dermal Transfer Factor for Cotton Scouts. Sacramento, CA: CDFA, Worker Health and Safety Branch. Available from: http://www.cdpr.ca.gov/docs/whs/memo/hsm90001.

California Energy Commission. 2006. California's Energy Efficiency Standards for Residential and Nonresidential Buildings. Sacramento, CA: California Energy Commission. http://www.energy.ca.gov/title24/index.html (accessed July 6, 2007).

California Environmental Protection Agency. 2004. *Guidance for School Site Risk Assessment Pursuant to Health and Safety Code Section 901(f): Guidance for Assessing Exposures and Health Risks at Existing and Proposed School Sites. Final Report*. Sacramento, CA: Office of Environmental Health Hazard Assessment.

Canadian Environmental Protection Act. 1999. *National Ambient Air Quality Objectives for Particulate Matter, Part 1: Science Assessment Document*. Ottawa (Canada): Canadian Environmental Protection Act/Federal–Provincial Advisory Committee (CEPA/FPAC) Working Group on Air Quality Objectives and Guidelines.

Caplan, K.J. 1993. The significance of wipe samples. *American Industrial Hygiene Association Journal* 53(2):70-75.

CDC. 1985. Polychlorinated biphenyl transformer incident–New Mexico. *Morbidity and Mortality Weekly Report* 34(36):557-559.

CDC. 2002. Comprehensive Procedures for Collecting Environmental Samples for Culturing *Bacillus anthracis*. http://www.bt.cdc.gov/agent/anthrax/environmental-sampling-apr2002.asp (accessed August 7, 2007).

Chavalitnitikul, C., and L. Levin. 1984. A laboratory evaluation of wipe testing based on lead oxide surface contamination. *American Industrial Hygiene Association Journal* 45(5):311-317.

Clothier, J.M. 2000. *Dermal transfer efficiency of pesticides from new, vinyl sheet flooring to dry and wetted palms*. EPA/600/R-00/029. Research Triangle Park, North Carolina: USEPA, Office of Research and Development (Contract No. 68-DO-0049). Available from: http://www.healthyhousing.org/clearinghouse/docs/Article0022.pdf.

Cohen Hubal, E.A., P.P. Egeghy, K.W. Leovic, and G.G. Akland. 2006. Measuring potential dermal transfer of a pesticide to children in a child care center. *Environmental Health Perspectives* 114(2):264-269.

Contaminants of Potential Concern (COPC) Committee of the World Trade Center (WTC) Indoor Air Work Group (IAWG). 2003. *World Trade Center Indoor Environment Assessment: Selecting Contaminants of Potential Concern and Setting Health-Based Benchmarks.* New York, NY: COPC Committee of the WTC IAWG. Available from: http://www.epa.gov/wtc/copc_benchmark.pdf.

Danish Environmental Protection Agency. 2003. Survey of chemicals in consumer products, no. 23: Survey of chemicals compounds in textile fabrics. Copenhagen (Denmark): DEPA, Danish Ministry of Environment and Energy.

Dennis Kunkel Microscopy, Inc. 2007. Scientific Stock Photography. Image Number: 251412D. http://www.denniskunkel.com (accessed May 2007).

DHHS (NIOSH). U.S. Public Health Service. 1994. DHHS (NIOSH) Publication No. 94-113. *NIOSH Manual of Analytical Methods (NMAM). Method 9100: Lead in Surface Wipe Samples.* Cincinnati: NIOSH.

DHHS (NIOSH). U.S. Public Health Service. 2003a. DHHS (NIOSH) Publication No. 2003-154, Suppl 3. *NIOSH Manual of Analytical Methods (NMAM). Method 9102: Elements on Wipes.* Cincinnati: NIOSH.

DHHS (NIOSH). U.S. Public Health Service. 2003b. DHHS (NIOSH) Publication No. 2003-154, Suppl 3. *NIOSH Manual of Analytical Methods (NMAM). Method 9105: Lead in Dust Wipes by Chemical Spot Test (Colorimetric Screening Method).* Cincinnati: NIOSH.

Dols, W.S., A.K. Persily, and S. J. Nabinger. 1995. NISTIR 5586. *Indoor Air Quality Commissioning of a New Office Building*. Proceedings from American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) IAQ '95: Practical Engineering for IAQ, October 22-24, 1995, Denver, Colorado, and National Conference on Building Commissioning, 3rd, May 1-5, 1995, Milwaukee, Wisconsin. Springfield, VA: U.S. Department of Commerce, National Technical Information Service (NTIS).

Dufay, S.K. 2005. *Comparison of collection efficiency of sampling methods for removable beryllium surface contamination.* Document #5237592, SAND #2005-7077C. Presented at the Beryllium Health and Safety Committee Meeting. Salt Lake City, UT.

Edwards, R.D., and P.J. Lioy. 1999. The EL sampler: a press sampler for the quantitative estimation of dermal exposure to pesticides in housedust. *Journal of Exposure Analysis and Environmental Epidemiology* 9(5):521-529.

EIA. 2006a. 2003 CBECS Detailed Tables. Washington, DC: Energy Information Administration. http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/detailed_tables_2003.html (accessed June 25, 2007).

EIA. 2006b. 2003 Commercial Buildings Energy Consumption Survey: How the Survey was Conducted. Washington, DC: Energy Information Administration. http://www.eia.doe.gov/emeu/cbecs/2003howconducted.html (accessed June 25, 2007).

Emmerich, S.J., and S.J. Nabinger. 2001. Technical Report NISTIR 6461. *Measurement and Simulation of the IAQ Impact of Particle Air Cleaners in a Single-Zone Building*. Gaithersburg, MD: U.S. Department of Commerce, National Institute of Standards and Technology (NIST).

Federal Register, Vol. 64, No. 235. 1999. *Chronic Beryllium Disease Prevention Program; Final Rule.* 8 December, 68854-68914. Available from: http://www.gpoaccess.gov/fr/search.html.

Federal Register, Vol. 66, No. 4. 2001. *Lead; Identification of Dangerous Levels of Lead.* 5 January, 1206-1211. Available from: http://www.epa.gov/fedrgstr/EPA-TOX/2001/January/Day-05/t84.pdf.

Fennie, J.E. 2005. *Space Planning: How Much Space Do You Really Need?* http://www.thespaceplace.net/articles/fennie200501a.htm (accessed October 11, 2007).

Fenske, R.A., and C. Lu. 1994. Determination of handwash removal efficiency: incomplete removal of the pesticide chlorpyrifos from skin by standard handwash techniques. *American Industrial Hygiene Association Journal* 55(5):425-432.

Ferro, A.R., R.J. Kopperud, and L.M. Hildemann. 2004. Source Strengths for Indoor Human Activities that Resuspend Particulate Matter. *Environmental Science and Technology* 38(6):1759-1764.

Fiserova-Bergerova, V., J.T. Pierce, and P.O. Droz. 1990. Dermal absorption potential of industrial chemicals: criteria for skin notation. *American Journal of Industrial Medicine* 17(5):617-635.

Fish, B.R., R.L. Walker, G.W. Royster, and J.L. Thompson. 1967. Redispersion of settled particulates. Proceedings of a symposium held at Gatlingur, Tennessee, June 1964. In *Surface Contamination*, ed. B.R. Fisher, 75-81. New York: Pergamon Press.

Fisk, W.J., D. Faulkner, D. Sullivan, and M.J. Mendell. 2000. Particle concentrations and sizes with normal and high efficiency air filtration in a sealed air-conditioned office building. *Aerosol Science and Technology* 32(6):527-544.

Fogh, C.L., M.A. Byrne, J. Roed, and A.J.H. Goddard. 1997. Size specific indoor aerosol deposition measurements and derived I/O concentrations ratios. *Atmospheric Environment* 31(15):2193-2203.

Freihaut, J.D., W.P. Bahnfleth, and B. Hu. 2005. *Phase II Task 2 Report: Modeling of Transient Aerosol Resuspension with Multizone Air Flow and Contaminant Distribution Software*. Contract No. DABJ05-03-P-1210. Prepared for the U.S. Army Center for Health Promotion and Preventive Medicine, Aberdeen Proving Ground, MD, by Pennsylvania State University, University Park, PA.

Gaborek, B.J., J.M. Mullikin, A.T. Pitrat, L. Cummings, and L.M. May. 2001. Pentagon surface wipe sampling health risk assessment. *Toxicology and Industrial Health* 17(5-10):254-261.

Gomes, C., J. Freihaut, and W. Bahnfleth. 2007. Resuspension of allergen-containing particles under mechanical and aerodynamic disturbances from human walking. *Atmospheric Environment* 41(25): 5257-5270.

Gurunathan, S., M. Robson, N. Freeman, B. Buckley, A. Roy, R. Meyer, J. Bukowski, and P.J. Lioy. 1998. Accumulation of chlorpyrifos on residential surfaces and toys accessible to children. *Environmental Health Perspectives* 106(1):9-16.

Healy, J.W. 1971. Surface Contamination: Decision Levels. Report No. LA-4558-MS. Los Alamos, NM: Los Alamos Scientific Laboratory.

Howard-Reed, C., L. Wallace, and S.J. Emmerich. 2003. NISTIR 7068. *Deposition Rates of Fine and Coarse Particles in Residential Buildings: Literature Review and Measurements in an Occupied Townhouse*. Gaithersburg, MD: U.S. Department of Commerce, National Institute of Standards and Technology.

Hughson, G.W., and J.W. Cherrie. 2005. Comparison of measured dermal dust exposures with predicted exposures given by the EASE expert system. *Annals of Occupational Hygiene* 49(2):111-123.

Ikezawa, Y, T. Okamoto, and A. Yabe. 1980. Experiences in monitoring airborne radioactive contamination in JAERI. In *Radiation protection: a systematic approach to safety: proceedings of the 5th Congress of the International Radiation Protection Society, Jerusalem*. New York: Pergamon Press.

Institute of Medicine. 2000. *Clearing the Air: Asthma and Indoor Air Exposures*. Committee on the Assessment of Asthma and Indoor Air, Division of Health Promotion and Disease Prevention, Institute of Medicine. Washington, DC: National Academy Press.

Johnson, T. 2002. *A Guide to Selected Algorithms, Distributions, and Databases Used in Exposure Models Developed by the Office of Air Quality Planning and Standards* (Revised Draft). Prepared for the USEPA Office of Research and Development, Research Triangle Park, NC, by TRJ Environmental, Inc., Chapel Hill, NC. Available from: http://www.epa.gov/ttn/fera/data/human/report052202.pdf.

Jones, I.S., and S.F. Pond. 1967. Some experiments to determine the resuspension factor of plutonium from various surfaces. In: *Surface Contamination*, ed. B.R. Fish. Oxford: Pergamon Press.

Khvostov, N.M., and M.S. Kostyakov. 1969. Hygienic significance of radioactive contamination of working surfaces. *Hygiene and Sanitation* (English edition) 34:43-48.

Kissel, J.C., J.H. Shirai, K.Y. Richter, and R.A. Fenske. 1998. Empirical investigation of hand-to-mouth transfer of soil. *Bulletin of Environmental Contamination and Toxicology* 60(3):379-386.

Ko, G., and H.A. Burge. 2004. Effects of furniture polish on release of car allergen-laden dust from wood surfaces. *Indoor Air* 14:434-438.

Lagus Applied Technology, Inc. 1995. *Air Change Rates in Non-Residential Buildings in California.* Report P400-91-034BCN. Prepared for the California Energy Commission, Sacramento, CA, by Lagus Applied Technology, Inc., San Diego, CA.

Lewis, R.G., C.R. Fortune, R.D. Willis, D.E. Camann, and J.T. Antley. 1999. Distribution of pesticides and polycyclic aromatic hydrocarbons in house dust as a function of particle size. *Environmental Health Perspectives* 107(9):721-726.

Lichtenwalner, C.P. 1992. Evaluation of Wipe Sampling Procedures and Elemental Surface Contamination. *American Industrial Hygiene Association Journal* 53(10):657-659.

Lioy, P.J., N.C. Freeman, and J.R. Millette. 2002. Dust: a metric for use in residential and building exposure assessment and source characterization. *Environmental Health Perspectives* 110(10):969-983.

Long, C.C., and A.Y. Finlay. 1991. The finger-tip unit–a new practical measure. *Clinical and Experimental Dermatology* 16(6): 444-447.

Long, C.M., H.H. Suh, and P. Kourtrakis. 2000. Characterization of indoor particle sources using continuous mass and size monitors. *Journal of the Air & Waste Management Association* 50(7):1236-1250.

Long, C.M., H.H. Suh, P.J. Catalano, and P. Koutrakis. 2001. Using time- and size-resolved particulate data to quantify indoor penetration and deposition behavior. *Environmental Science and Technology* 35(10):2089-2099.

Loosmore, G.A. 2003. Evaluation and development of models for resuspension of aerosols at short times after deposition. *Atmospheric Environment* 37(5):639-647.

Lu, C., and R.A. Fenske. 1999. Dermal transfer of chlorpyrifos residues from residential surfaces: comparison of hand press, hand drag, wipe, and polyurethane foam roller measurements after broadcast and aerosol pesticide applications. *Environmental Health Perspectives* 107(6):463-467.

May, L.M., B. Gaborek, T. Pitrat, and L. Peters. 2002. Derivation of risk based wipe surface screening levels for industrial scenarios. *Science of the Total Environment* 288(1-2):65-80.

McArthur, B. 1992. Dermal Measurement and Wipe Sampling Methods: A Review. *Applied Occupational and Environmental Hygiene* 7(9):599-606

McArthur, B.R., and P.S.J. Lees. 1995. Effect of Contact Time and Contack Pressure on the Transfer of Oil to Surface Sample Media. *Applied Occupational and Environmental Hygiene* 10(1):23-27.

Michaud, J.M., S.L. Huntley, R.A. Sherer, M.N. Gray, and D.J. Paustenbach. 1994. PCB and Dioxin Re-Entry Criteria for Building Surfaces and Air. *Journal of Exposure Analysis and Environmental Epidemiology* 4(2):197-227.

Miniño, A.M., M.P. Heron, S.L. Murphy, and K.D. Kochanek. 2007. Deaths: Final Data for 2004. *National Vital Statistics Reports* 55:19. (Note: Tables 3 and 5 have been revised as of October 10, 2007.)

Mølhave, L., T. Schneider, S.K. Kjægaard, L. Larsen, S. Norn, and O. Jørgensen. 2000. House dust in seven Danish offices. *Atmospheric Environment* 34(28):4767-4779.

Na, K., and D.R. Cocker. 2005. Organic and elemental carbon concentrations in fine particulate matter in residences, schoolrooms, and outdoor air in Mira Loma, California. *Atmospheric Environment* 39(18):3325-3333.

National Research Council. 2005. *Reopening Public Facilities After a Biological Attack: A Decision-Making Framework*. Washington, DC: National Academies Press. Available from: http://www.nap.edu/catalog.php?record_id=11324.

Ness, S.A. 1994. *Surface and Dermal Monitoring for Toxic Exposures*. New York: John Wiley & Sons, Inc.

Nishioka, M.G., R.G. Lewis, M.C. Brinkman, H.M. Burkholder, C.E. Hines, and J.R. Menkedick. 2001. Distribution of 2,4-D in air and on surfaces inside residences after lawn applications: comparing exposure estimates from various media for young children. *Environmental Health Perspectives* 109(11):1185-1191.

NYSDOH. 1985. Document 1330P: PCB Re-entry Guidelines. Albany, NY: New York State Department of Health, Bureau of Toxic Substance Assessment, Division of Environmental Health Assessment.

Offermann, F.J., R.G. Sextro, W.J. Fisk, D.T. Grimsrud, W.W. Nazaroff, A.V. Nero, K.L. Revzan, and J. Yater. 1985. Control of respirable particles in indoor air with portable air cleaners. *Atmospheric Environment* 19(11): 1761-1771.

Ogden, C.L., C.D. Fryar, M.D. Carroll, and K.M. Flegal. 2004. Mean body weight, height, and body mass index, United States 1960-2002. *Advance Data from Vital and Health Statistics* 347: 1-17.

Oppl, R., F. Kalberlah, P.G. Evans, and J.J. van Hemmen. 2003. A toolkit for dermal risk assessment and management: an overview. *Annals of Occupational Hygiene* 47(8):629-640.

OSHA. 1989. Method ID-145: Particulate Mercury in Workplace Atmospheres. http://www.osha.gov/dts/sltc/methods/inorganic/id145/id145.html (accessed August 6, 2007).

OSHA. 1991. Method ID-105: Inorganic Arsenic in Workplace Atmospheres. http://www.osha.gov/dts/sltc/methods/inorganic/id105/id105.html (accessed August 6, 2007).

OSHA. 1999. TED 01-00-015, OSHA Technical Manual (OTM). http://www.osha.gov/dts/osta/otm/otm_toc.html (accession date unknown).

OSHA. 2001. Method W4001: Hexavalent Chromium. http://www.osha.gov/dts/sltc/methods/validated/t-w4001-fv-02-0104-m/t-w4001-fv-02-0104-m.html (accessed August 7, 2007).

OSHA. 2002a. Method ID-121: Metal & Metalloid Particulates in Workplace Atmospheres (Atomic Absorption). http://www.osha.gov/dts/sltc/methods/inorganic/id121/id121.html (accessed August 6, 2007).

OSHA. 2002b. Method ID-125G: Metal and Metalloid Particulates in Workplace Atmospheres (ICP Analysis). http://www.osha.gov/dts/sltc/methods/inorganic/id125g/id125g.html (accessed August 6, 2007).

OSHA. 2002c. Method W4002: 1,6-Hexamethylene Diisocyanate. http://www.osha.gov/dts/sltc/methods/validated/w4002/w4002.html (accessed August 7, 2007).

OSHA. 2007. *Evaluation Guidelines for Surface Sampling Methods.* Report No. T-006-01-0104-M. Salt Lake City, UT: OSHA Salt Lake Technical Center. http://www.osha.gov/dts/sltc/methods/surfacesampling/surfacesampling.html (accessed March 28, 2008).

Parsons Engineering Science, Inc. 1997. Risk *assessment of PCBs in non-liquid materials at Robins Air Force Base, Georgia, Bolling Air Force Base, Washington, D.C., and Andrews Air Force Base, Maryland*. Pasadena, CA: Parsons Engineering Science, Inc.

Persily, A.K., and R.A. Grot. 1985. *Ventilation System Performance Evaluation Using Tracer Gas Techniques*. Paper 26, Ventilation Strategies and Measurement Techniques, 6th AIC Conference, September 16-19, 1985, Netherlands. Gaithersburg, MD: U.S. Department of Commerce, National Bureau of Standards.

Persily, A.K. 1989. *Ventilation Rates in Office Buildings*. Proceedings of IAQ '89, The Human Equation: Health and Comfort, San Diego, 128-136.

Persily, A., and J. Gorfain. 2004. Technical Report No. NISTIR 7145. *Analysis of Ventilation Data from the U.S. Environmental Protection Agency Building Assessment Survey and Evaluation (BASE) Study*. Gaithersburg, MD: U.S. Department of Commerce, National Institute of Standards and Technology (NIST).

Persily, A., J. Gorfain, and G. Brunner. 2005. Ventilation design and performance in U.S. office buildings. *ASHRAE Journal* 47(4):30-35.

Que Hee, S.S., B. Peace, C.S. Clark, J.R. Boyle, R.L. Bornschein, and P.B. Hammond. 1985. Evolution of efficient methods to sample lead sources, such as house dust and hand dust, in the homes of children. *Environmental Research* 38(1):77-95.

Ramwell, C.T., P.D. Johnson, and H. Corns. 2006. Transferability of six pesticides from agricultural sprayer surfaces. *Annals of Occupational Hygiene* 50(3):323-329.

Rasmussen, P.E. 2004. Can metal concentrations in indoor dust be predicted from soil geochemistry? *Canadian Journal of Analytical Sciences and Spectroscopy* 49(3):166-174.

Reifenrath, W.G., H.O. Kammen, W.G. Palmer, M.M. Major, and G.J. Leach. 2002. Percutaneous Absorption of Explosives and Related Compounds: An Empirical Model of Bioavailability of Organic Nitro Compounds from Soil. *Toxicology and Applied Pharmacology* 182:160-168.

Reynolds, S.J., L. Etre, P.S. Thorne, P. Whitten, M. Selim, and W.J. Popendorf. 1997. Laboratory Comparison of Vacuum, OSHA, and HUD Sampling Methods for Lead in Household Dust. *American Industrial Hygiene Association Journal* 58:439-446.

Rodes, C.E., J.R. Newsome, R.W. Vanderpool, J.T. Antley, and R.G. Lewis. 2001. Experimental methodologies and preliminary transfer factor data for estimation of dermal exposures to particles. *Journal of Exposure Analysis and Environmental Epidemiology* 11(2):123-139.

Ross, J., T. Thongsinthusak, H.R. Fong, S. Margetich, and R. Krieger. 1990. Measuring potential dermal transfer of surface pesticide residue generated from indoor fogger use: an interim report. *Chemosphere* 20(3-4):349-360.

Rusin, P., S. Maxwell, and C. Gerba. 2002. Comparative surface-to-hand and fingertip-to-mouth transfer efficiency of gram-positive bacteria, gram-negative bacteria, and phage. *Journal of Applied Microbiology* 93:585-592.

Sansone, E.B. 1987. Redispersion of indoor surface contamination and its implication. In *Treatise on Clear Surface Technology*, *Volume 1*, ed. K.L. Mittal, 261-290. New York: Plenum Press.

Shapiro, J. 1970. Tests for the evaluation of airborne hazards from radioactive surface contamination. *Health Physics* 19(4):501-510.

Simonson, M. 2006. Office building becomes toxic tower. *The Daily Star*, January 30.

Slayton, T.M., P.A. Valberg, and A.D. Wait. 1998. Estimating dermal transfer from PCB-contaminated porous surfaces. *Chemosphere* 36(14):3003-3014.

Sutton, G.H.C. 2004. Enumeration of total airborne bacteria, yeast and mold contaminants and identification of *Escherichia coli* O157:H7, *Listeria* Spp., *Salmonella* Spp., and *Staphylococcus* Spp. in a beef and pork slaughter facility. Dissertation, University of Florida.

Tagg, B. 1966. Determination of the resuspension of plutonium arising from contaminated surfaces in a plutonium operational area. In Society for Radiological Protection, International Symposium on the Radiological Protection of the Worker by the Design and Control of His Environment. Burnemouth, England.

Thatcher, T.L., and D.W. Layton. 1995. Deposition, resuspension, and penetration of particles within a residence. *Atmospheric Environment* 29(13):1487-1497.

Thatcher, T.L., T.E. McKone, W.J. Fisk, M.D. Sohn, W.W. Delp, W.J. Riley, and R.G. Sextro. 2001. Technical Report No. LBNL-49321. *Factors Affecting the Concentration of Outdoor Particles Indoors (COPI): Identification of Data Needs and Existing Data.* (Contract No. AC03-76SF00098). Berkeley, CA: Lawrence Berkeley National Laboratory, Environmental Energy Technologies Division.

Thatcher, T.L., C.K. Lai, R. Moreno-Jackson, R.G. Sextro, and W.W. Nazaroff. 2002. Effects of room furnishings and air speed on particle deposition rates indoors. *Atmospheric Environment* 36:1811-1819.

Tickner, J., J. Friar, K.S. Creely, J.W. Cherrie, D.E. Pryde, and J. Kingston. 2005. The Development of the EASE Model. *Annals of Occupational Hygiene* 49(2):103-110.

Title 10, Code of Federal Regulations, Part 850.31, Release criteria, 2007. Available from: http://www.access.gpo.gov/nara/cfr/waisidx_08/10cfr850_08.html

Title 24, Code of Federal Regulations (CFR), Part 35, Subpart R–Method and Standards for Lead-Paint Hazard Evaluation and Hazard Reduction Activities, 2008. Available from: http://www.gpoaccess.gov/cfr/index.html.

Title 40, CFR, Section 152, Pesticide Registration and Classification Procedures, 2005. Available from: http://www.gpoaccess.gov/cfr/index.html.

Title 40, CFR, Section 158, Data Requirements for Registration, 2005. Available from: http://www.gpoaccess.gov/cfr/index.html.

Title 40, CFR, Section 300.430, Remedial investigation/feasibility study and selection of remedy, 2008. Available from: http://www.gpoaccess.gov/cfr/index.html.

Title 40, CFR, Section 761.123, Definitions, 2006. Available from: http://www.gpoaccess.gov/cfr/index.html.

Turk, B.H., D.T. Grimsrud, J.T. Brown, K.L. Geisling-Sobotka, J. Harrison, and R.J. Prill. 1989. Commercial building ventilation rates and particle concentrations. *ASHRAE Transactions* 95(1):422-433.

USACHPPM. 1998. Memorandum, USACHPPM, MCHB-TS-EHM, 26 May 1998, subject: Hazardous Waste Study No. 37-EF-6209-98, WRAIR Chemical Decommissioning, Building 500 Phase I Pilot Project, Walter Reed Army Medical Center, Forest Glen Campus, 1-5 December 1997.

USACHPPM. 1999a. USACHPPM Project No. 39-EJ-1157-99. Interim Report. *Derivation of Wipe Surface Screening Levels for Environmental Chemicals: Industrial Scenarios*. Aberdeen Proving Ground, MD: USACHPPM.

USACHPPM. 1999b. Derivation of Health-Based Environmental Screening Levels for Chemical Warfare Agents: A Technical Evaluation. Aberdeen Proving Ground, MD: USACHPPM.

USACHPPM. 2003. Memorandum, USACHPPM, MCHB-TS-TTE, 20 July 2003, subject: Investigation of Potential Transfer from Hands to Cigarettes of SERPACWA. (Toxicology Study No. 85-XC-6716-02, HSSRB Log No. A-11100, Investigation of Potential Transfer from Hands to Cigarettes of SERPACWA, September 2002)

USACHPPM. 2006a. *SOP No. DEHE-03-006: Standing Operating Procedure (SOP) for the Collection of Surface Wipe Samples.* Aberdeen Proving Ground, MD: USACHPPM.

USACHPPM. 2006b. *SOP No. 39-01-03: Standard Operating Procedure for Selection and Development of Chronic Toxicity Criteria for Human Health Risk Assessment.* Aberdeen Proving Ground, MD: USACHPPM.

USACHPPM. 2007. *Development of Fate and Transport Parameter Datasets for Use in Environmental Health Risk Assessments, Version 4*. Aberdeen Proving Ground, MD: USACHPPM.

USACHPPM. 2008. *SOP No. 39-06-03: Standard Operating Procedure for Chemical Classification Schemes Useful for Environmental Health Risk Databases*. Aberdeen Proving Ground, MD: USACHPPM.

USEPA. 1985. EPA/560/5-85/026. *Verification of PCB Spill Cleanup by Sampling and Analysis.* Washington, DC: USEPA, Office of Toxic Substances. Available from: http://www.epa.gov/osw/hazard/tsd/pcbs/pubs/sampling.pdf.

USEPA. 1986. EPA/560/5-86/017. *Field Manual for Grid Sampling of PCB Spill Sites to Verify Cleanup.* Washington, DC: USEPA, Office of Toxic Substances. Available from: http://www.epa.gov/epawaste/hazard/tsd/pcbs/pubs/gridsampling.pdf.

USEPA. 1989a. EPA/600/8-89/043. Exposure Factors Handbook, Assessing Exposure. Washington, DC: USEPA, Office of Research and Development.

USEPA. 1989b. EPA/540/1-89/002. *Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual (Part A).* Washington, DC: USEPA, Office of Emergency and Remedial Response. Available from: http://www.epa.gov/oswer/riskassessment/ragsa/pdf/rags-vol1-pta_complete.pdf.

USEPA. 1990. Integrated Risk Information System: Vinyl acetate (CASRN 108-05-4). Washington, DC: Office of Research and Development. http://www.epa.gov/iris/subst/0512.htm (accessed June 18, 2007).

USEPA. 1991. Office of Solid Waste and Emergency Response (OSWER) Directive 9285.6-03. Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual, Supplemental Guidance, "Standard Default Exposure Factors" Interim Final. Washington, DC: USEPA, Office of Emergency and Remedial Response.

USEPA. 1992a. EPA/600/Z-92/001. *Guidelines for Exposure Assessment.* Washington, DC: USEPA. Available from: http://rais.ornl.gov/homepage/GUIDELINES_EXPOSURE_ASSESSMENT.pdf.

USEPA. 1992b. EPA/600/8-91/011B. Interim Report. *Dermal Exposure Assessment: Principles and Applications.* Washington, DC: USEPA, Exposure Assessment Group, Office of Health and Environmental Assessment. Available from: http://www.epa.gov/ncea/pdfs/dermalexp.pdf.

USEPA. 1994. EPA/600/8-90/066F. *Methods for Derivation of Inhalation Reference Concentrations and Application of Inhalation Dosimetry*. Washington, DC: Office of Research and Development.

USEPA. 1995a. *Residential Sampling for Lead: Protocols for Dust and Soil Sampling: Final Report.* MRI Project No. 9803. Work Assignment No. 4-10(02). Washington, DC: USEPA, Office of Pollution Prevention and Toxics.

USEPA. 1995b. EPA/747/R-95/007. *Final Report. Sampling House Dust for Lead: Basic Concepts and Literature Review.* Washington, DC: USEPA, Office of Pollution Prevention and Toxics (Office of Prevention, Pesticides, and Toxic Substances).

USEPA. 1997a. *Draft Standard Operating Procedures (SOPs) for Residential Exposure Assessments.* Contract No. 68-W6-0030. Work Assignment No. 3385.102. Washington, DC: USEPA, Residential Exposure Assessment Work Group. Available from: http://www.epa.gov/oppfead1/trac/science/trac6a05.pdf.

USEPA. 1997b. EPA/600/P-95/002Fa. Exposure Factors Handbook, Volume I: General Factors. Washington, DC: USEPA, Office of Research and Development.

USEPA. 1997c. EPA/600/P-95/002Fc. Exposure Factors Handbook, Volume III: Activity Factors. Washington, DC: USEPA, Office of Research and Development.

USEPA. 1998a. EPA/747/R-97/006. *Risk Analysis to Support Standards for Lead in Paint, Dust, and Soil.* Washington, DC: USEPA, Office of Pollution Prevention and Toxics. Available from: http://www.epa.gov/lead/pubs//toc.pdf.

USEPA. 1998b. Toxic Substances Control Act (TSCA) Section 403: Sampling Guidance for Identifying Lead-Based Paint Hazards. Public Review Draft. Washington, DC: USEPA: Office of Pollution Prevention and Toxics.

USEPA. 1999. REx: R*esidential* Ex*posure Assessment, Generic Methods. Case Study: Lawn Care Products.* Washington, DC: OP Case Study Group, Non-Dietary Subcommittee.

USEPA. 2001. EPA/600/R-03/026. *Draft Protocol for Measuring Children's Non-Occupational Exposure to Pesticides by All Relevant Pathways*. Research Triangle Park, NC: National Exposure Research Laboratory, Office of Research and Development.

USEPA. 2003a. *EPA Region 3 Risk-Based Concentration Table: Technical Background Information* (Updated November 18, 2008). Philadelphia, PA: USEPA Region 3. Available from: http://www.epa.gov/reg3hwmd/risk/human/info/tech.htm

USEPA. 2003b. Memorandum, Director of Office of Superfund Remediation and Technology Innovation, 5 December 2003, subject: Human Health Toxicity Values in Superfund Risk Assessments. OSWER Directive 9285.7-53. Washington, DC: USEPA, Office of Solid Waste and Emergency Response. Available from: http://rais.ornl.gov/homepage/hhmemo.pdf.

USEPA. 2003c. Memorandum from Jeffrey Dawson to Anthony Britten, 20 February 2003, subject: Revised Phase 5 Occupational and Residential Exposure Assessment and Recommendations for the Reregistration Eligibility Decision Document. Washington, DC: Office of Prevention, Pesticides and Toxic Substances.

USEPA. 2003d. EPA/540/R-03/001. *Recommendations of the Technical Review Workgroup for Lead for an Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil.* Washington, DC: Technical Review Workgroup for Lead. Available from: http://epa.gov/superfund/lead/products/adultpb.pdf

USEPA. 2003e. *Updated Dermal Exposure Assessment Guidance*. Philadelphia, PA: USEPA Region 3. Available from: http://www.epa.gov/reg3hwmd/risk/human/info/dermalag.htm

USEPA. 2004a. EPA/600/P-99/002aF. *Air Quality Criteria for Particulate Matter, Volume 1*. Research Triangle Park, NC: USEPA, Office of Research and Development.

USEPA. 2004b. EPA/540/R-99/005. *Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment).* Washington, DC: USEPA, Office of Superfund Remediation and Technology Innovation. Available from: http://www.epa.gov/oswer/riskassessment//ragse/pdf/introduction.pdf.

USEPA. 2004c. *Users' Guide and Background Technical Document for USEPA Region 9's Preliminary Remediation Goals (PRG) Table.* San Francisco, CA: USEPA Region 9. Available from: http://www.epa.gov/region09/superfund/prg/files/04usersguide.pdf.

USEPA. 2005a. EPA/630/P-03/003F. *Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants.* Washington, DC: Risk Assessment Forum. Available from: http://www.epa.gov/raf/publications/pdfs/AGEGROUPS.PDF

USEPA. 2005b. USEPA Report No. OPPT-2004-0123. Polychlorinated Biphenyl (PCB) Site Revitalization Guidance Under the Toxic Substances Control Act (TSCA). Washington, DC: Office of Pollution Prevention and Toxics. Available from: http://www.epa.gov/osw/hazard/tsd/pcbs/pubs/pcb-guid3-06.pdf

USEPA. 2005c. *World Trade Center Residential Dust Cleanup Program: Final Report.* Prepared by USEPA Region 2, New York City Response and Recovery Operations, New York, NY, with technical assistance from Syracuse Research Corporation, Syracuse, NY.

USEPA. 2007a. EPA/600/R-07/004. *A Literature Review of Wipe Sampling Methods for Chemical Warfare Agents and Toxic Industrial Chemicals.* Washington, DC: USEPA, Office of Research and Development. Available from: http://www.epa.gov/NHSRC/pubs.html.

USEPA. 2007b. *IAQ Building Education and Assessment Model (I-BEAM), Glossary of Terms.* Washington, DC: USEPA. Available from: http://www.epa.gov/iaq/largebldgs/i-beam/glossary.html.

USEPA. 2007c. *IAQ Building Education and Assessment Model (I-BEAM), Text Modules: Heating, Ventilation, and Air-conditioning (HVAC).* Washington, DC: USEPA, Office of Radiation and Indoor Air. Available from: http://www.epa.gov/iaq/largebldgs/i-beam/text/hvac.html

USEPA 2007d. EPA/425/R-07/004. *Ozone Population Exposure Analysis for Selected Urban Areas.* Research Triangle Park, NC: USEPA, Office of Air Quality Planning and Standards.

USEPA. 2007e. *Particulate Matter: Basic Information.* Research Triangle Park, NC: USEPA, Office of Air Quality Planning and Standards. http://www.epa.gov/air/particlepollution/basic.html (accessed June 1, 2007).

USEPA. 2008. *Integrated Risk Information System.* Washington, DC: USEPA, Office of Research and Development, National Center for Environmental Assessment. http://www.epa.gov/iriswebp/iris/ (accessed April 2008).

Van Cuyk, S., R. L. Siegrist , K. Loew, J. Drewes, J. Munakata-Marr, and L. Figueroa. 2005. *Performance of Engineered Treatment Units and Their Effects on Biozone Formation in Soil and System Purification Efficiency*. Project No. WU-HT-03-36. Prepared for the National Decentralized Water Resources Capacity Development Project, Washington University, St. Louis, MO, by the Colorado School of Mines, Golden, CO.

Vette, A.F., A.W. Rea, P.A. Lawless, C.E. Rodes, G. Evans, V.R. Highsmith, and L. Sheldon. 2001. Characterization of indoor-outdoor aerosol concentration relationships during the Fresno PM exposure studies. *Aerosol Science and Technology* 34:118-126.

Voss, J. 2000. *Revisiting Office Space Standards*. Holland, MI: Haworth, Inc.

Wallace, L. 1996. Indoor particles: a review. *Journal of the Air & Waste Management Association* 46(2):98-126.

Wallace, L.A., J. Quackenboss, and C. Rodes. 1997. Continuous measurements of particles, PAH, and CO in an occupied townhouse in Reston, VA. In: Measurement of Toxic and Related Air Pollutants, Proceedings of EPA-AWMA Symposium on Toxic and Related Compounds, Research Triangle Park, NC, 860-871. Pittsburgh, PA: Air & Waste Management Association.

Wheeler, J.P., and J.D. Stancliffe. 1998. Comparison of Methods for Monitoring Solid Particulate Surface Contamination in the Workplace. *Annals of Occupational Hygiene* 42(7): 477-488.

WHO. 2004. *IPCS Risk Assessment Terminology: IPCS Harmonization Project Document No. 1*. Geneva, Switzerland: World Health Organization (International Programme on Chemical Safety).

Wolfe, H.R., J.F. Armstrong , D.C. Staiff, and S.W. Comer. 1975. Potential exposure of workers to parathion through contamination of cigarettes. *Bulletin of Environmental Contamination and Toxicology* 13(3):369-376.

WSDOH. 2005. *Rationale for the Establishment of the Washington State Department of Health's Clandestine Drug Lab Program Decontamination Standards.* (WAC 246-205-541). Olympia, WA: WSDOH, Office of Environmental Health and Safety. Available from: http://www.doh.wa.gov/ehp/ts/CDL/default.htm

Xu, M., M. Nematollahi, R.G. Sextro, A.J. Gadgil, and W.W. Nazaroff. 1994. Deposition of tobacco smoke particles in a low ventilation room. *Aerosol Science and Technology* 20(2):194-206.

Young, R. 2007. *The Evolving American Office* (by Allsteel®). (Allsteel® is a registered trademark of Hon Industries, Inc. Muscatine, IA.) http://www.thespaceplace.net/articles/allsteel200708a.htm (accessed October 10, 2007).

Yu, C. D.J. LePoire, J.J. Cheng, E. Gnanapragasam, S. Kamboj, J. Arnish, B.M. Biwer, A.J. Zielen, W.A. Williams, A. Wallo III, and H.T. Peterson, Jr. 2003. ANL/EAD/03-1. *User's Manual for RESRAD-BUILD Version 3*. Contract No. W-31-109-Eng-38 (U.S. Department of Energy). Argonne, IL: Argonne National Laboratory.

Zainudin, A., and S. Semple. 2005. *Determination of the Factors Influencing Transfer of Chemicals from the Work Environment to the Skin and Hence from Hands to the Peri-oral Area.* First International Occupational Hygiene Association (IOHA) International Scientific Conference in Africa, September 19-23. South Africa: Pilanesberg National Park.

APPENDIX B
EXISTING AND PREVIOUSLY DOCUMENTED METHODS

This appendix provides a summary of past and existing methods used to evaluate potential health effects from exposure to surface contaminants. Theoretical models that have not previously been implemented and methods that are not publicly available are not included in the discussion.

B.1 New York State Department of Health

In 1985, the New York State Department of Health (NYSDOH) developed re-entry guidelines for PCBs, which included "possible" air and surface guidelines (NYSDOH 1985). These guidelines were prepared in response to a fire in the Binghamton State Office Building which caused a transformer to explode, leaving the building uninhabitable (Simonson 2006).

To determine whether exposure to building surfaces was safe, surface guidelines were derived for a worker exposed to surface contaminants via direct dermal contact and incidental ingestion. The mass transferred from surface to the skin was estimated by assuming 25 percent of both arms (0.070 m^2) would contact the contaminated surface per workday. Since there was no discussion of the fraction of contaminant actually transferred, this meant 100 percent of the material on the contacted surface was presumed to be transferred to the skin. In addition, the worker was assumed to incidentally ingest contaminants from an area equal to 5 percent of the surface area of both hands (0.0033 m^2). Similarly, 100 percent transfer efficiency was assumed. These fractions were used to modify the contaminant surface concentration to estimate the daily intake as shown in equation B-1.

Equation B-1

$$Intake = C_s \cdot (a_i \cdot 0.0033 + a_d \cdot 0.070)$$

Where:

C_s = contaminant concentration on surfaces (μg/m^2)
a_i = fraction of ingested contaminant that is absorbed
a_d = dermal absorption fraction

The NYSDOH was a member of the COPC Committee of the WTC IAWG, which established health-based benchmarks for selected surface contaminants (see paragraph B-6).

B.2 U.S. Environmental Protection Agency Region III

In 1997, Parsons Engineering Science, Inc., prepared a draft risk assessment report for evaluating potential health risks from exposures to non-liquid polychlorinated biphenyls (NLPCBs) at a typical Air Force base (Parsons Engineering Science, Inc. 1997). The exposure pathways included direct contact, incidental ingestion, and inhalation of NLPCBs in building materials. The source of methodology for assessing direct and indirect dermal contacts was a document titled *USEPA Region III Generic Guidance for Assessing Wipe Samples*. It is unclear whether Region III actually implemented this guidance as attempts to locate this guidance in its previous or current form were unsuccessful.

The Region III equations for assessing direct dermal contact with a building surface and incidental ingestion of contaminants on the hands are shown below. The method includes some mass balance considerations where the amount of contaminant available for dermal absorption is adjusted by the amount "removed" from the hands via incidental ingestion ($1\text{-}FT_{sm}$ in equation B-2B).

Equation B-2

A)

$$D_s = C \cdot SA \cdot CF \cdot FT_{ss} \cdot EF \cdot ED$$

B)

$$D_d = \frac{D_s \cdot (1 - FT_{sm}) \cdot ABS_d}{BW \cdot AT}$$

C)

$$D_o = \frac{D_s \cdot FT_{sm} \cdot ABS_o}{BW \cdot AT}$$

Where:

D_s = amount of chemical deposited on skin (mg)
C = concentration of chemical on contaminated surface (mg/cm^2)
SA = exposed skin surface area (cm^2)
CF = contact frequency of skin against surface (1/day)
FT_{ss} = fraction transferred from surface to skin (unitless)
EF = exposure frequency (days/year)
ED = exposure duration (years)
D_d = dermal dose (mg/kg/day)
FT_{sm} = fraction transferred from skin to mouth (unitless)
ABS_d = dermal absorption fraction (unitless)
BW = body weight (kg)
AT = averaging time (days)
D_o = oral dose (mg/kg/day)
ABS_o = oral absorption fraction (unitless)

The Region III guidance did not include inhalation of resuspended surface contaminants. Since Parsons Engineering Science, Inc., worked with actual air concentrations taken from air samplers, they did not have to develop a model to estimate the resuspended surface contaminant concentration.

B.3 U.S. Environmental Protection Agency Residential Exposure Assessment Work Group

In response to the requirements of the Food Quality Protection Act (FQPA) of 1996, the USEPA developed an SOP for evaluating nonoccupational exposures to pesticide residues from multiple sources (USEPA 1997a). Revisions to this SOP have been used by the Office of Prevention, Pesticides and Toxic Substances to complete its residential exposure assessment of carbaryl (USEPA 2003c). The SOPs provide algorithms for estimating exposures via dermal contact, ingestion, and inhalation of pesticides during handling or post application.

B.3.1 Dermal Exposure

The crux of the dermal exposure algorithm is the use of a transfer coefficient (TC), which is a ratio of the dermal exposure over a given time (for example, milligrams per hour (mg/hr)) to either the total or the transferable residue (for example, mg/cm^2) (California Department of Food and Agriculture (CDFA) 1990; USEPA 2001). Since this results in units of area over time (for example, square centimeters per hour (cm^2/hr)), in theory, the TC represents the total skin area

exposed for a specific activity. Thus, an activity with numerous repeated surface contacts would have a larger TC.

The 1997 SOPs recommended mean TC values of 43,000 cm^2/hr and 8,700 cm^2/hr for adults and toddlers (ages 1–6), respectively. The adult value was estimated based on adults performing Jazzercise routines, and the toddler value adjusted by applying a body surface area ratio to the adult TC (USEPA 1997a). These TCs were considered representative upper bound estimates as Jazzercise involves greater surface contacts compared to other indoor activities. Although not discussed in the SOPs, the adult TC was apparently derived from Ross et al. (1990) who measured the potential transfer of pesticide residue to volunteers performing Jazzercise routines. These initial default values have subsequently been revised to 16,700 cm^2/hr and 6,000 cm^2/hr for the adult and toddler, respectively (Cohen Hubal et al. 2006; COPC Committee of the WTC IAWG 2003). It is unknown what type of activity the revised adult TC is based on although derivation of the toddler value remains the same (Cohen Hubal et al. 2006).

Even though the SOPs provide default TCs for residential exposures, the main drawback of using a TC to estimate dermal exposure is the lack of data. This limitation was also noted by USEPA Region III which stated TC data is "no more available than information about frequency of skin contact" (Parsons Engineering Science, Inc., 1997). The USEPA Office of Pesticides has compiled measured exposure data for various pesticide handler scenarios (USEPA 1999). Originally developed for agricultural workers in the field, the Pesticide Handlers Exposure Database (PHED) now includes exposure data for residential settings as well (40 CFR 152 (2005), 40 CFR 158 (2005)). Still, the PHED may have limited applications for the purposes of this TG because it contains exposure data only for pesticide handlers. A closer examination of data in the PHED may be conducted in the future to determine whether the data may be used as surrogate data for some chemicals and for the exposure scenarios in TG 312. Transfer coefficient data for nonpesticides is not expected to be forthcoming because there is currently no policy to drive funding in that area. In addition, TC values for nonoccupational scenarios are more difficult to estimate because of the noncontrolled manner in which chemicals "appear" on surfaces and the numerous ways in which a receptor may encounter surface contaminants.

B.3.2 Incidental Ingestion

The SOPs provide algorithms for exposure to different activities, one of which involves exposure to pesticide residues on hard surfaces. A potential dose rate from incidental ingestion of surface contaminants is estimated as follows:

Equation B-3

$$PDR = ISR \cdot SA \cdot FQ \cdot ET$$

Where:

PDR = potential dose rate (mg/day)
ISR = indoor surface residue (mg/cm^2)
SA = surface area of the anatomical body part that contacts indoor surfaces and then transfers residues to the mouth in a given event (cm^2/hr)
FQ = frequency of hand-to-mouth events (events/hr)
ET = exposure time (hrs/day)

When measured ISR data is not available, the ISR is estimated from pesticide-specific application information. Note equation B-3 does not use a TC but permits users to apply a hand-to-mouth event frequency. Since not every dermal contact is associated with a hand-to-mouth contact, using a TC to estimate the potential ingestion dose rate would require adjusting the TC with a fraction to account for those dermal contacts that result in a hand-to-mouth contact.

B.3.3 Inhalation

The SOPs do not provide methods for estimating inhalation exposure to resuspended particles. Therefore, no summary of the inhalation pathways in the SOPs is presented in this TG.

B.4 U.S. Army Center for Health Promotion and Preventive Medicine

The USACHPPM prepared an interim report that provided surface screening levels for industrial scenarios (USACHPPM 1999a). Methods used to estimate exposures via dermal contact and incidental ingestion were similar to the NYSDOH method presented above with modifications to the input parameters and different nomenclature.

Equation B-4

A)

$$CR_{derm} = C_s \cdot F_d \cdot SA_d \cdot DAF$$

B)

$$CR_{ing} = C_s \cdot F_g \cdot SA_g$$

Where:

CR_{derm} = dermal contact rate (mg/day)
C_s = surface concentration (milligram per square meter (mg/m^2))
Fd = fraction of available surface area contacted (1/day)
SA_d = amount of skin that may contact a surface (m^2)
DAF = dermal absorption efficiency (unitless)
CR_{ing} = ingestion contact rate (mg/day)
F_g = fraction of available surface area transferred to mouth (1/day)
SA_g = surface area available for ingestion (m^2)

The report also included inhalation of resuspended dust or other surface particles using the following expression:

Equation B-5

$$CR_{inh} = C_s \cdot K \cdot IR_{inh}$$

Where:

CR_{inh} = inhalation contact rate (mg/day)
C_s = surface concentration (mg/m^2)
K = resuspension factor (1/m)
IR_{inh} = inhalation rate (m^3/day)

Equation B-5 was derived from information provided by the Massachusetts Department of Environmental Protection (MADEP) in response to a health risk assessment prepared by the U.S. Army (USACHPPM 1999a). In their recommendation, the MADEP provided two possible alternatives for estimating resuspension of surface particulate matters. The first, the adopted method, was based on a relationship where the ratio of resuspended air concentration to the surface concentration results in a resuspension ("K") factor. This simple relationship was originally developed by health physicists for evaluating resuspension of radionuclides indoors (Caplan 1993). The second method provided by MADEP relied on standard industrial hygiene ventilation models but was deemed not applicable "in a general sense" because it required making significant assumptions concerning site-specific data (USACHPPM 1999a).

The USACHPPM approach was updated by May and her colleagues who developed health-based screening levels using principles presented in the USEPA Region III guidance, as well as the USEPA Region IX method for deriving preliminary remediation goals (PRGs). Region IX PRGs

are risk-based concentrations that combine multiple pathways of exposure for receptors exposed to a specific medium (USEPA 2004c).

May developed screening levels for industrial and construction worker scenarios using three explosives as test substances (May et al. 2002). The workers were presumed to potentially be exposed to surface contaminants from direct dermal contact, incidental ingestion from hand-to-mouth transfer, and from inhalation of resuspended particles. The equation for estimating inhalation of resuspended particles was the same as equation B-5 except May expressed the inhalation contact rate in different units (m^2/day). Formulas for estimating direct dermal contact and incidental ingestion of surface contaminants are as follows:

Equation B-6

A) $$CR_{derm} = SA_d \cdot F_d \cdot EV \cdot FT_{ss} \cdot DAF$$

B) $$CR_{ing} = SA_g \cdot F_g \cdot EV \cdot FT_{ss} \cdot FT_{ftm} \cdot HTME$$

Where:

CR_{derm} = dermal contact rate (m^2/day)
SA_d = dermal surface area available for absorption (m^2)
Fd = fraction of available dermal area contacted per day (unitless)
EV = contact frequency with surface (1/day)
FT_{ss} = fraction of dust transferred from surface to skin (unitless)
DAF = dermal absorption efficiency (unitless)
CR_{ing} = ingestion contact rate (m^2/day)
SA_g = dermal surface area available for ingestion (m^2)
F_g = fraction of available dermal area that contacts the mouth (unitless)
FT_{ftm} = fraction of dust transferred from skin to mouth (unitless)
HTME = hand-to-mouth events (unitless)

The May methodology, which was pending publication on 11 September 2001, was used to derive risk-based screening levels for PCBs, dioxins, and furans to assess potential health risks from exposure to surface contaminants at the Pentagon after the attack (Gaborek et al. 2001). Gaborek et al (2001) modified EPs to reflect those of an office worker rather than an industrial or construction worker as in May (2002).

B-5. USEPA National Exposure Research Laboratory

To better address the requirements of the FQPA, the USEPA is taking steps to improve exposure data for children and infants. This effort is being conducted by the National Exposure Research Laboratory (NERL), which is one of the research facilities of the USEPA Office of Research and Development. The NERL has published a draft protocol for estimating children's exposure to pesticides in nonoccupational scenarios (USEPA 2001).

The draft protocol presents two alternatives for estimating direct and indirect contact with surface residues. In the microactivity approach, dermal exposure is estimated by summing exposures for discrete dermal contact events of short duration. This method uses a transfer efficiency (TE) to estimate contaminant transfer to the portal of entry (that is, skin or mouth). By contrast, the macroactivity approach uses a TC to estimate exposure. Examples of macroactivities include sleeping and eating (USEPA 2001). The general formulas for estimating exposure under either approach are as follows:

Equation B-7

A) $$E_{ma} = C_{surf} \cdot TC \cdot AD$$

B) $$E_{mi} = C_{surf} \cdot TE \cdot SA \cdot EF$$

Where:

E_{ma} = dermal exposure based on macroactivity approach (µg/day)
C_{surf} = surface loading measured in the microenvironment (µg/cm^2)
TC = transfer coefficient (cm^2/hr)
AD = activity duration for macroactivity in a specific microenvironment (hr/day)
E_{mi} = dermal (or indirect ingestion) exposure based on microactivity approach (µg/day)
TE = transfer efficiency (from surface to skin if dermal; object to mouth if ingestion) (unitless)
SA = surface area contacted (object area if ingestion) (cm^2/event)
EF = frequency of contact events over a 24-hr period (events/day)

The TE represents the fraction of mass transferred from a contaminated surface to the skin or to the mouth for each contact event (USEPA 2001). Recall from above that a TC is based on repeated contacts with a contaminated surface for a specific activity. While the TE is unitless, a TC has units of cm^2/hr.

B.6 World Trade Center Indoor Air Task Force Working Group

The collapse of the WTC in 2001 prompted health concerns to nearby residents who may have been exposed to contaminants that had migrated indoors. This led to the formation of a multiagency task force, which consisted of both Federal and state agencies, to assess potential health risks to nearby residents. In addition to monitoring indoor air quality, the task force also considered health risks posed from exposure to residues on indoor surfaces (COPC Committee of the WTC IAWG 2003).

To address these concerns, the task force developed health-based benchmarks with which wipe sample results could be compared. These benchmarks were developed based on both direct contact with indoor surfaces and incidental ingestion from hand-to-mouth transfer (COPC Committee of the WTC IAWG 2003). Inhalation of resuspended particles was not included as air quality was monitored by taking actual air samples.

B.6.1 Dermal Exposure

The task force opted to use the TC method presented in the USEPA SOPs, with modifications to account for a different exposure group (COPC Committee of the WTC IAWG 2003). The following equation was used to estimate the daily skin load expressed in μg/cm^2:

Equation B-8

$$Daily\ Skin\ Load = \frac{\left(TC \cdot ET_{hard} \cdot FT_{ss_{hard}} \cdot CSL_{hard}\right) + \left(TC \cdot ET_{soft} \cdot FT_{ss_{soft}} \cdot CSL_{soft}\right)}{SA}$$

Where:

TC = transfer coefficient (cm^2/hr)
ET = exposure time to hard surfaces (for example, kitchen surfaces) or soft surfaces (for example, carpet) (hr/day)
FT_{ss} = fraction transferred from (hard or soft) surface to the skin (unitless)
CSL = contaminant surface load (hard or soft) (μg/cm^2)
SA = exposed skin surface area (cm^2)

The parameter, FT_{ss}, in equation B-8 modifies the contaminant surface load to account for only the transferable fraction. The amount transferred to the skin was estimated by using a TC.

B.6.2 Incidental Ingestion

For incidental ingestion, the task force adopted a model similar to the one recommended in the SOPs (see equation B-3) except for an additional saliva extraction factor. This is the fraction transferred from the skin to the mouth and is dependent on chemical and behavioral patterns (COPC Committee of the WTC IAWG 2003).

B.7 United Kingdom Health and Safety Executive

The United Kingdom has developed a computer model for evaluating occupational exposures to chemicals (Tickner et al. 2005). Although the Estimation and Assessment of Substance Exposure (EASE) model has been in use since the early 1990s, nothing about its development or principles had ever been published until 2005 (Tickner et al. 2005).

The EASE model estimates both inhalation and dermal exposures using chemical-specific and activity-specific information. Since inhalation exposures are modeled after industrial activities and not necessarily limited to resuspension of settled particles, that part of the EASE model is not discussed further. Dermal exposures are estimated by grouping occupational activities into one of four contact levels, and the pattern for use. The contact levels range from "none" (no contact) to "extensive" (more than 11 events per day) (Tickner et al. 2005). The pattern for use is assigned based on whether an activity results in wide or limited dispersal effects (Hughson and Cherrie 2005). Resulting dermal exposure is expressed as a mass per skin surface area per day ($mg/cm^2/day$). Workplace inhalation exposures similarly consider parameters limited to industrial-type activities.

Validation exercises to test the dermal exposure predictions of the EASE model indicate the model consistently overestimates dermal exposure (Hughson and Cherrie 2005). The developers of EASE acknowledge that the dermal exposure portion of the model is "very rudimentary" as it was developed at a time when limited information on dermal exposure was available (Tickner et al. 2005). Also, EASE contains only exposure data from industry in the United Kingdom which limits its application for use by other countries (Tickner et al. 2005).

B.8 The European Commission RISKOFDERM

The Risk Assessment of Occupational Dermal Exposure to Chemicals, or RISKOFDERM, describes a research project funded by the European Commission with the purpose of developing a conceptual model to evaluate potential health risks from dermal exposures in the workplace (Oppl et al. 2003). The research also involved the development of a "toolkit" to implement the conceptual model and to help users make risk management decisions with respect to

occupational dermal exposures (Opp1 et al. 2003). The toolkit does not evaluate occupational exposures via inhalation or incidental ingestion (Oppl et al. 2003).

The toolkit evaluates different types of dermal exposures (for example, immersion), including exposure to surface contamination resulting from handling contaminated tools (Oppl et al. 2003). Although default exposure rates are available, users may adjust these default values with modifying factors to account for the actual degree of exposure. The model also permits users to adjust dermal exposure with the amount of clothing worn by a worker. For example, the potential exposure rate (units of $mg/cm^2/hr$) is adjusted by a factor of 0.5 if the worker is attired in "light clothing" (Oppl et al. 2003). The toolkit also evaluates local health effects (for example, itching) and systemic health effects separately because the mechanisms that lead to either effect are very different (Oppl et al. 2003).

B.9 Office of Environmental Health Hazard Assessment, California Environmental Protection Agency

Responding to state regulatory requirements, the California Environmental Protection Agency (Cal/EPA) developed a guidance for evaluating potential health risks to school employees and students at existing and proposed school sites (Cal/EPA 2004). Among the various exposure pathways discussed, the guidance also recommends inclusion of direct dermal contact and incidental ingestion of dust that has infiltrated school buildings and settled onto surfaces and inhalation of resuspended indoor dust (Cal/EPA 2004). However, the method estimated substance concentration in indoor dust by applying a transfer factor to the soil concentration because the source of indoor dust is presumed to come from the school yard. Therefore, soil sample results and not wipe sample results are used to estimate substance concentration in indoor dust.

B.10 Summary of All Methods

Table B-1 summarizes the known past and existing methods as described above. In general, although models such as EASE and RISKOFDERM are available for use, their application is limited to occupational settings where the types of activities leading to dermal contact are vastly different from those of an office worker or a resident. The repetitive nature of many industrial or agricultural tasks (for example, grinding metal parts or picking strawberries) permits measurement of dermal contact rates for a wide range of activities. Dermal contact rates are usually estimated for exposures to a specific agent while conducting a certain activity and over a given exposure period (for example, $mg/cm^2/hr$). The concept is analogous to a TC, discussed above, which estimates the hourly dermal exposure while conducting a specific task.

The lack of dermal contact rates or TC for nonoccupational settings makes it more difficult to apply models that rely on these parameters. However, the paradigms implemented by these models are still applicable for evaluating any population of concern. For example, RISKOFDERM divides tasks into groups using factors such as degree of exposure or amount of clothing worn. This concept may also be applied to residential groups to develop a default range of EPs.

Table B-1. Summary of Past and Existing Methods for Evaluating Wipe Sample Data

SOURCE OR METHOD	PATHWAY CONSIDERED			EXPOSURE GROUP CONSIDERED	
	DIRECT DERMAL CONTACT[1]	INCIDENTAL INGESTION	INHALATION OF RESUSPENDED PARTICLES	OCCUPATIONAL (INDUSTRIAL OR AGRICULTURAL)	NON-OCCUPATIONAL (INCLUDING OFFICE WORKER)
New York State Department of Health	☐TC ☒TE/FT_{SS}	☒	☐	☐	☒
USEPA Region III	☐TC ☒TE/FT_{SS}	☒	☐	☐	☐
USEPA Residential Exposure Assessment Work Group	☒TC ☐TE/FT_{SS}	☒	☐	☐	☒
U.S. Army Center for Health Promotion and Preventive Medicine	☐TC ☒TE/FT_{SS}	☒	☒	☒	☐
USEPA National Exposure Research Laboratory	☒TC ☒TE/FT_{SS}	☒	☐	☐	☒
World Trade Center Indoor Air Task Force Working Group	☒TC ☐TE/FT_{SS}	☒	☐	☐	☒
United Kingdom Health and Safety Executive	☒TC ☐TE/FT_{SS}	☐	☐	☒	☐
The European Commission RISKOFDERM	☒TC ☐TE/FT_{SS}	☐	☐	☒	☐
Office of Environmental Hazard Assessment, Cal/EPA[1]	☐TC ☐TE/FT_{SS}	☒	☒	☐	☒

Notes:
[1] Does not rely on data from wipe sampling

APPENDIX C
SURFACE WIPE SCREENING LEVELS

This appendix provides a table with surface wipe screening levels (SWSL) for a list of substances most commonly sampled by the USACHPPM Hazardous and Medical Waste Program. The list includes chemical warfare agents (CWA), a dioxin, explosives (EXP), herbicides (HERB), metals (MET), pesticides (PEST), and semi-volatile organic compounds (SVOC).

Table C-1. Surface Wipe Screening Levels Based on Target Cancer Level of 1E-06 and Target Hazard Quotient of 1

Class	Chemical Name	CASRN	Detection Limit[a,b,c] (µg/100 cm^2)	FINAL SWSL (µg/100 cm^2)	Basis
CWA	GB	107-44-8	2.50E-01	8.83E-01	nc
CWA	Thiodiglycol	111-48-8	1.00E+00	1.83E+05	nc
CWA	Diisopropyl methylphosphonate	1445-75-6	2.50E-01	1.37E+04	nc
CWA	Ethyl methylphosphonic acid	1832-53-7	1.00E+00	3.79E+03	nc
CWA	Isopropyl methyl phosphonic acid	1832-54-8	1.00E+00	1.72E+04	nc
CWA	Lewisite oxide	3088-37-7	1.00E+00	1.48E+01	nc
CWA	1,4-Dithiane	505-29-3	4.00E-01	1.72E+03	nc
CWA	Sulfur mustard (or H/HD)	505-60-2	5.00E-01	5.00E-01	DL
CWA	VX	50782-69-9	2.50E-01	2.50E-01	DL
CWA	S-(Diisopropylaminoethyl) methyl-phosphonothioic acid	73207-98-4	5.00E-01	5.00E-01	DL
CWA	Methylphosphonic acid	993-13-5	1.00E+00	3.39E+02	nc
Dioxin	2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)	1746-01-6	2.00E-06	3.54E-05	c
EXP	2,4,6-Trinitrotoluene	118-96-7	1.00E+00	9.07E+01	c
EXP	2,4-Dinitrotoluene	121-14-2	1.00E+00	3.65E+00	c
EXP	RDX	121-82-4	1.00E+00	3.62E+01	c
EXP	HMX	2691-41-0	2.00E+00	3.76E+04	nc
EXP	Tetryl	479-45-8	1.00E+00	3.73E+03	nc
EXP	Nitroglycerin	55-63-0	1.00E+00	1.20E+02	c
EXP	2,6-Dinitrotoluene	606-20-2	1.00E+00	1.73E+02	nc
EXP	2-Nitrotoluene	88-72-2	1.00E+00	5.22E+00	c
EXP	Nitrobenzene	98-95-3	1.00E+00	8.27E+01	nc
EXP	3-Nitrotoluene	99-08-1	1.00E+00	3.43E+03	nc
EXP	1,3,5-Trinitrobenzene	99-35-4	1.00E+00	1.54E+04	nc
EXP	1,3-Dinitrobenzene	99-65-0	1.00E+00	1.72E+01	nc
EXP	4-Nitrotoluene	99-99-0	1.00E+00	1.20E+02	c

Table C-1. Surface Wipe Screening Levels Based on Target Cancer Level of 1E-06 and Target Hazard Quotient of 1 (continued)

Class	Chemical Name	CASRN	Detection Limit[a,b,c] (µg/100 cm^2)	FINAL SWSL (µg/100 cm^2)	Basis
HERB	Dicamba	1918-00-9	4.00E-01	5.15E+03	nc
HERB	Picloram	1918-02-1	4.00E-01	1.20E+04	nc
HERB	Bentazon	25057-89-0		5.15E+03	nc
HERB	Pentachlorophenol	87-86-5	4.00E-01	4.47E+00	c
HERB	Mecoprop (MCPP)	93-65-2	4.00E+01	1.72E+02	nc
HERB	2,4,5-TP	93-72-1	4.00E-01	1.37E+03	nc
HERB	Trichlorophenoxyacetic acid (2,4,5-T)	93-76-5	4.00E-01	1.72E+03	nc
HERB	2-Methyl-4-chlorophenoxyacetic acid (MCPA)	94-74-6	4.00E+01	8.58E+01	nc
HERB	2,4-D	94-75-7	4.00E-01	2.91E+03	nc
HERB	4-(2,4-Dichlorophenoxy)butyric acid (2,4-DB)	94-82-6	2.00E+00	1.37E+03	nc
MET	Chromium, trivalent	16065-83-1	4.00E-01[d]	5.94E+04	nc
MET	Chromium hexavalent ion	18540-29-9	5.00E-03	9.48E-01	c
MET	Aluminum	7429-90-5	**2.00E+01**	5.66E+03	nc
MET	Iron	7439-89-6	**2.00E+01**	6.91E+05	nc
MET	Manganese	7439-96-5	2.00E+00	5.67E+01	nc
MET	Mercury	7439-97-6	2.00E-01	5.12E+02	nc
MET	Molybdenum	7439-98-7	2.00E+00	4.93E+03	nc
MET	Nickel	7440-02-0	5.00E+00	4.74E+01	c
MET	Silver	7440-22-4	2.00E+00	5.76E+02	nc
MET	Strontium	7440-24-6	**4.00E+00**	5.92E+05	nc
MET	Tin	7440-31-5	**4.00E+01**	5.92E+05	nc
MET	Titanium	7440-32-6	**1.00E+02**	4.83E+04	nc
MET	Arsenic	7440-38-2	2.00E+00	2.00E+00	DL
MET	Barium	7440-39-3	2.00E+00	5.60E+02	nc
MET	Beryllium	7440-41-7	2.00E+00	4.74E+00	c
MET	Boron	7440-42-8	**4.00E+01**	2.91E+04	nc
MET	Cadmium	7440-43-9	2.00E+00	6.32E+00	c
MET	Cobalt	7440-48-4	2.00E+00	1.71E+02	nc
MET	Copper	7440-50-8	2.00E+00	3.65E+05	nc
MET	Vanadium	7440-62-2	2.00E+00	6.94E+02	nc
MET	Zinc	7440-66-6	**2.00E+01**	2.96E+05	nc
MET	Selenium	7782-49-2	5.00E+00	4.31E+03	nc
PEST	Heptachlor epoxide	1024-57-3	1.50E-01	1.50E-01	DL
PEST	Aroclor 1254	11097-69-1	1.60E+00	1.60E+00	DL

Table C-1. Surface Wipe Screening Levels Based on Target Cancer Level of 1E-06 and Target Hazard Quotient of 1 (continued)

Class	Chemical Name	CASRN	Detection Limit[a,b,c] (µg/100 cm^2)	FINAL SWSL (µg/100 cm^2)	Basis
PEST	Endosulfan	115-29-7	1.50E-01	1.03E+03	nc
PEST	Hexachlorobenzene	118-74-1	1.50E-01	7.18E-01	c
PEST	Malathion	121-75-5	2.00E+00	3.43E+03	nc
PEST	Simazine	122-34-9	3.00E+00	1.00E+01	c
PEST	Aroclor 1016	12674-11-2	1.60E+00	9.04E+00	nc
PEST	Terbufos	13071-79-9	2.00E+00	4.29E+00	nc
PEST	Propazine	139-40-2	3.00E+00	3.43E+03	nc
PEST	Trifluralin	1582-09-8	5.00E-01	1.56E+02	c
PEST	Alachlor	15972-60-8	5.00E-01	2.14E+01	c
PEST	Dimethyl tetrachloroterephthalate (DCPA; Dacthal)	1861-32-1	1.00E+00	1.72E+03	nc
PEST	Benefin	1861-40-1	5.00E-01	5.15E+04	nc
PEST	Chlorothalonil	1897-45-6	1.00E+00	3.71E+02	c
PEST	Atrazine	1912-24-9	3.00E+00	5.22E+00	c
PEST	Oxadiazon	19666-30-9	3.00E-01	8.58E+02	nc
PEST	Mirex	2385-85-5	3.00E-01	3.00E-01	DL
PEST	Pronamide	23950-58-5	3.00E+00	1.29E+04	nc
PEST	Chlorpyrifos	2921-88-2	2.00E+00	5.15E+02	nc
PEST	Methyl parathion	298-00-0	2.00E+00	4.29E+01	nc
PEST	Phorate	298-02-2	5.00E+00	3.43E+01	nc
PEST	Disulfoton	298-04-4	3.00E+00	6.86E+00	nc
PEST	Ronnel	299-84-3	2.00E+00	8.58E+03	nc
PEST	Aldrin	309-00-2	1.50E-01	1.50E-01	DL
PEST	beta-Hexachlorocyclohexane (beta-BHC; beta-HCH)	319-85-7	1.50E-01	6.37E-01	c
PEST	Diazinon	333-41-5	2.00E+00	1.20E+02	nc
PEST	Chlorofenvinphos	470-90-6	2.00E+00	1.20E+02	nc
PEST	p,p'-DDT	50-29-3	3.00E-01	7.51E+00	c
PEST	Vinclozolin	50471-44-8	2.00E+00	4.29E+03	nc
PEST	Permethrin	52645-53-1	2.00E+00	8.58E+03	nc
PEST	Chlorpyrifos methyl	5598-13-0	2.00E+00	1.72E+03	nc
PEST	Ethion	563-12-2	2.00E+00	8.58E+01	nc
PEST	Parathion (Parathion-ethyl)	56-38-2	2.00E+00	1.03E+03	nc
PEST	Chlordane	57-74-9	1.50E-01	6.14E+00	c
PEST	Lindane (gamma-BHC)	58-89-9	5.00E-01	1.82E+00	c
PEST	Dimethoate	60-51-5	5.00E+00	3.43E+01	nc
PEST	Dieldrin	60-57-1	1.50E-01	1.50E-01	DL
PEST	Dichlorvos	62-73-7	3.00E+00	3.96E+00	c

Table C-1. Surface Wipe Screening Levels Based on Target Cancer Level of 1E-06 and Target Hazard Quotient of 1 (continued)

Class	Chemical Name	CASRN	Detection Limit[a,b,c] (µg/100 cm^2)	FINAL SWSL (µg/100 cm^2)	Basis
PEST	Endrin	72-20-8	3.00E-01	5.15E+01	nc
PEST	Methoxychlor	72-43-5	1.50E+00	8.58E+02	nc
PEST	p,p'-DDD	72-54-8	3.00E-01	4.79E+00	c
PEST	p,p'-DDE	72-55-9	1.50E-01	3.53E+00	c
PEST	Phosmet	732-11-6	3.00E+00	3.43E+03	nc
PEST	Heptachlor	76-44-8	1.50E-01	2.55E-01	c
PEST	Toxaphene	8001-35-2	6.00E+00	6.00E+00	DL
PEST	Pentachloronitrobenzene	82-68-8	1.00E+00	4.62E+00	c
PEST	Fonofos	944-22-9	2.00E+00	3.43E+02	nc
PEST	Tetrachlorvinphos [iso]	961-11-5	3.00E+00	5.00E+01	c
SVOC	4-Nitroaniline	100-01-6	2.00E+01	6.00E+01	c
SVOC	Benzyl alcohol	100-51-6	2.00E+01	8.58E+04	nc
SVOC	2,4-Dimethylphenol	105-67-9	2.00E+01	3.43E+03	nc
SVOC	p-Cresol	106-44-5	2.00E+01	8.58E+02	nc
SVOC	1,4-Dichlorobenzene	106-46-7	2.00E+01	1.67E+02	c
SVOC	4-Chloroaniline	106-47-8	2.00E+01	6.86E+02	nc
SVOC	Phenol	108-95-2	2.00E+01	4.20E+04	nc
SVOC	Bis(2-chloroethyl) ether	111-44-4	2.00E+01	2.00E+01	DL
SVOC	Bis(2-ethylhexyl)phthalate	117-81-7	2.00E+01	8.35E+01	c
SVOC	Di-n-octyl phthalate	117-84-0	2.00E+01	6.86E+03	nc
SVOC	Anthracene	120-12-7	2.00E+01	4.20E+04	nc
SVOC	1,2,4-Trichlorobenzene	120-82-1	2.00E+01	3.34E+02	c
SVOC	2,4-Dichlorophenol	120-83-2	2.00E+01	5.15E+02	nc
SVOC	Pyrene	129-00-0	2.00E+01	4.06E+03	nc
SVOC	Dibenzofuran	132-64-9	2.00E+01	3.43E+02	nc
SVOC	Indeno(1,2,3-cd)pyrene	193-39-5	2.00E+01	2.00E+01	DL
SVOC	Benz(b)fluoranthene	205-99-2	2.00E+01	2.00E+01	DL
SVOC	Fluoranthene	206-44-0	2.00E+01	5.38E+03	nc
SVOC	Benzo(k)fluoranthene	207-08-9	2.00E+01	2.00E+01	DL
SVOC	Chrysene	218-01-9	2.00E+01	1.11E+02	c
SVOC	Bis(2-chloro-1-methylethyl) ether[e]	108-60-1	2.00E+01	2.00E+01	DL
SVOC	Benzo(a)pyrene	50-32-8	2.00E+01	2.00E+01	DL
SVOC	2,4-Dinitrophenol	51-28-5	2.00E+01	3.43E+02	nc
SVOC	4,6-Dinitro-o-cresol	534-52-1	2.00E+01	2.00E+01	DL
SVOC	Dibenzo(a,h)anthracene	53-70-3	2.00E+01	2.00E+01	DL
SVOC	1,3-Dichlorobenzene	541-73-1	2.00E+01	4.86E+02	nc
SVOC	Benz(a)anthracene	56-55-3	2.00E+01	2.00E+01	DL
SVOC	3-Methyl-4-chlorophenol	59-50-7	2.00E+01	1.72E+04	nc

Table C-1. Surface Wipe Screening Levels Based on Target Cancer Level of 1E-06 and Target Hazard Quotient of 1 (continued)

Class	Chemical Name	CASRN	Detection Limit[a,b,c] (µg/100 cm^2)	FINAL SWSL (µg/100 cm^2)	Basis
SVOC	N-Nitrosodi-N-propylamine	621-64-7	2.00E+01	2.00E+01	DL
SVOC	N-Nitrosodimethylamine	62-75-9	2.00E+01	2.00E+01	DL
SVOC	Hexachloroethane	67-72-1	2.00E+01	8.31E+01	c
SVOC	Hexachlorocyclopentadiene	77-47-4	2.00E+01	1.86E+02	nc
SVOC	Isophorone	78-59-1	2.00E+01	1.26E+03	c
SVOC	Acenaphthene	83-32-9	2.00E+01	8.08E+03	nc
SVOC	Diethyl phthalate	84-66-2	2.00E+01	1.37E+05	nc
SVOC	Dibutyl phthalate	84-74-2	2.00E+01	1.72E+04	nc
SVOC	Butyl benzyl phthalate	85-68-7	2.00E+01	3.43E+04	nc
SVOC	N-nitrosodiphenylamine	86-30-6	2.00E+01	2.26E+02	c
SVOC	Hexachloro-1,3-butadiene	87-68-3	2.00E+01	2.00E+01	DL
SVOC	2,4,6-Trichlorophenol	88-06-2	2.00E+01	1.04E+02	c
SVOC	2-Nitroaniline	88-74-4	2.00E+01	9.32E+01	nc
SVOC	Naphthalene	91-20-3	2.00E+01	2.00E+01	DL
SVOC	2-Methylnaphthalene	91-57-6	2.00E+01	5.51E+02	nc
SVOC	2-Chloronaphthalene	91-58-7	2.00E+01	1.10E+04	nc
SVOC	o-Cresol	95-48-7	2.00E+01	8.58E+03	nc
SVOC	1,2-Dichlorobenzene	95-50-1	2.00E+01	1.45E+04	nc
SVOC	2-Chlorophenol	95-57-8	2.00E+01	8.58E+02	nc
SVOC	2,4,5-Trichlorophenol	95-95-4	2.00E+01	1.72E+04	nc
SVOC	3-Nitroaniline	99-09-2	2.00E+01	4.92E+01	nc

Notes:
[a]Assumes a 100 cm^2 wipe area.
[b]Adjusted from mass/wipe (see appendix D).
[c]Bold values = estimated DL; validated DL not available.
[d]Based on the detection limit for total chromium.
[e]bis (2-chloroisopropyl) ether often incorrectly listed as a synonym.

Legend:
CASRN = Chemical Abstracts Service Registry Number
nc = noncancer
DL = detection limit
c = cancer

APPENDIX D
ANALYTICAL DETECTION LIMITS USED TO DEVELOP SURFACE WIPE SCREENING LEVELS

This appendix lists detection limits in units of mass per wipe. The detection limits listed in this appendix are limits that can reasonably be expected to be achieved by a capable laboratory using the analytical method specified.

Table D-1. Analytical Detection Limits

Class	Chemical Name	CASRN	Practical Quantitation Limits[a]	Analytical Technique[b]
CWA	GB	107-44-8	0.25 µg/wipe	GC-FPD
CWA	Thiodiglycol	111-48-8	1 µg/wipe	IC
CWA	Diisopropyl methylphosphonate	1445-75-6	0.25 µg/wipe	GC-FPD
CWA	Ethyl methylphosphonic acid	1832-53-7	1 µg/wipe	IC
CWA	Isopropyl methyl phosphonic acid	1832-54-8	1 µg/wipe	IC
CWA	Lewisite oxide	3088-37-7	1 µg/wipe	IC
CWA	1,4-Dithiane	505-29-3	0.4 µg/wipe	GC-FPD
CWA	Sulfur mustard (or H/HD)	505-60-2	0.5 µg/wipe	GC-FPD
CWA	VX	50782-69-9	0.25 µg/wipe	GC-FPD
CWA	S-(Diisopropylaminoethyl) methyl-phosphonothioic acid	73207-98-4	0.5 µg/wipe	IC
CWA	Methylphosphonic acid	993-13-5	1 µg/wipe	IC
Dioxin	2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)	1746-01-6	2 pg/wipe	HRGC-HRMS
EXP	2,4,6-Trinitrotoluene	118-96-7	1 µg/wipe	GC-ECD
EXP	2,4-Dinitrotoluene[c]	121-14-2	1 µg/wipe	GC-ECD
EXP	RDX	121-82-4	1 µg/wipe	GC-ECD
EXP	HMX	2691-41-0	2 µg/wipe	GC-ECD
EXP	Tetryl	479-45-8	1 µg/wipe	GC-ECD
EXP	Nitroglycerin	55-63-0	1 µg/wipe	GC-ECD
EXP	2,6-Dinitrotoluene[c]	606-20-2	1 µg/wipe	GC-ECD
EXP	2-Nitrotoluene	88-72-2	1 µg/wipe	GC-ECD
EXP	Nitrobenzene[c]	98-95-3	1 µg/wipe	GC-ECD
EXP	3-Nitrotoluene	99-08-1	1 µg/wipe	GC-ECD
EXP	1,3,5-Trinitrobenzene	99-35-4	1 µg/wipe	GC-ECD
EXP	1,3-Dinitrobenzene	99-65-0	1 µg/wipe	GC-ECD
EXP	4-Nitrotoluene	99-99-0	1 µg/wipe	GC-ECD

Table D-1. Analytical Detection Limits (continued)

Class	Chemical Name	CASRN	Practical Quantitation Limits[a]	Analytical Technique[b]
HERB	Dicamba	1918-00-9	0.4 µg/wipe	GC-ECD
HERB	Picloram	1918-02-1	0.4 µg/wipe	GC-ECD
HERB	Bentazon[d]	25057-89-0	0.4 µg/wipe[d]	GC-ECD
HERB	Pentachlorophenol[c]	87-86-5	0.4 µg/wipe	GC-ECD
HERB	Mecoprop (MCPP)	93-65-2	40 µg/wipe	GC-ECD
HERB	2,4,5-TP	93-72-1	0.4 µg/wipe	GC-ECD
HERB	Trichlorophenoxyacetic acid (2,4,5-T)	93-76-5	0.4 µg/wipe	GC-ECD
HERB	2-Methyl-4-chlorophenoxyacetic acid (MCPA)	94-74-6	40 µg/wipe	GC-ECD
HERB	2,4-D	94-75-7	0.4 µg/wipe	GC-ECD
HERB	4-(2,4-Dichlorophenoxy)butyric acid (2,4-DB)	94-82-6	2 µg/wipe	GC-ECD
MET	Chromium, trivalent[e]	16065-83-1	2 µg/wipe[e]	ICP or ICP-MS
MET	Chromium hexavalent ion	18540-29-9	0.02 µg/wipe	IC
MET	Aluminum[d]	7429-90-5	50–100 µg/wipe[d]	ICP or ICP-MS
MET	Iron[d]	7439-89-6	25 µg/wipe[d]	ICP
MET	Manganese	7439-96-5	2 µg/wipe	ICP-MS
MET	Mercury	7439-97-6	0.2 µg/wipe	ICP-MS (or CVAA)
MET	Molybdenum	7439-98-7	2 µg/wipe	ICP-MS
MET	Nickel	7440-02-0	5 µg/wipe	ICP-MS
MET	Silver	7440-22-4	2 µg/wipe	ICP-MS
MET	Strontium[d]	7440-24-6	25 µg/wipe[d]	ICP
MET	Tin[d]	7440-31-5	50 µg/wipe[d]	ICP
MET	Titanium[d]	7440-32-6	100 µg/wipe[d]	ICP
MET	Arsenic	7440-38-2	2 µg/wipe	ICP-MS
MET	Barium	7440-39-3	2 µg/wipe	ICP-MS
MET	Beryllium	7440-41-7	2 µg/wipe	ICP-MS
MET	Boron[d]	7440-42-8	50 µg/wipe[d]	ICP
MET	Cadmium	7440-43-9	2 µg/wipe	ICP-MS
MET	Cobalt	7440-48-4	2 µg/wipe	ICP-MS
MET	Copper	7440-50-8	2 µg/wipe	ICP-MS
MET	Vanadium	7440-62-2	2 µg/wipe	ICP-MS
MET	Zinc[d]	7440-66-6	10–25 µg/wipe[d]	ICP or ICP-MS
MET	Selenium	7782-49-2	5 µg/wipe	ICP-MS
PEST	Heptachlor epoxide	1024-57-3	0.15 µg/wipe	GC-ECD
PEST	Aroclor 1254	11097-69-1	1.6 µg/wipe	GC-ECD
PEST	Endosulfan	115-29-7	0.15 µg/wipe	GC-ECD
PEST	Hexachlorobenzene[c,d]	118-74-1	0.15 µg/wipe[d]	GC-ECD

Table D-1. Analytical Detection Limits (continued)

Class	Chemical Name	CASRN	Practical Quantitation Limits[a]	Analytical Technique[b]
PEST	Malathion	121-75-5	2 µg/wipe	GC-ECD
PEST	Simazine	122-34-9	3 µg/wipe	GC-ECD
PEST	Aroclor 1016	12674-11-2	1.6 µg/wipe	GC-ECD
PEST	Terbufos	13071-79-9	2 µg/wipe	GC-ECD
PEST	Propazine	139-40-2	3 µg/wipe	GC-ECD
PEST	Trifluralin	1582-09-8	0.5 µg/wipe	GC-ECD
PEST	Alachlor	15972-60-8	0.5 µg/wipe	GC-ECD
PEST	Dimethyl tetrachloroterephthalate (DCPA; Dacthal)	1861-32-1	1 µg/wipe	GC-ECD
PEST	Benefin	1861-40-1	0.5 µg/wipe	GC-ECD
PEST	Chlorothalonil[d]	1897-45-6	1 µg/wipe[d]	GC-ECD
PEST	Atrazine	1912-24-9	3 µg/wipe	GC-ECD
PEST	Oxadiazon	19666-30-9	0.3 µg/wipe	GC-ECD
PEST	Mirex	2385-85-5	0.3 µg/wipe	GC-ECD
PEST	Pronamide[d]	23950-58-5	3 µg/wipe[d]	GC-ECD
PEST	Chlorpyrifos	2921-88-2	2 µg/wipe	GC-ECD
PEST	Methyl parathion	298-00-0	2 µg/wipe	GC-ECD
PEST	Phorate	298-02-2	5 µg/wipe	GC-ECD
PEST	Disulfoton	298-04-4	3 µg/wipe	GC-ECD
PEST	Ronnel	299-84-3	2 µg/wipe	GC-ECD
PEST	Aldrin	309-00-2	0.15 µg/wipe	GC-ECD
PEST	beta-Hexachlorocyclohexane (beta-BHC; beta-HCH)	319-85-7	0.15 µg/wipe	GC-ECD
PEST	Diazinon	333-41-5	2 µg/wipe	GC-ECD
PEST	Chlorofenvinphos	470-90-6	2 µg/wipe	GC-ECD
PEST	p,p'-DDT	50-29-3	0.3 µg/wipe	GC-ECD
PEST	Vinclozolin[d]	50471-44-8	2 µg/wipe[d]	GC-ECD
PEST	Permethrin	52645-53-1	2 µg/wipe	GC-ECD
PEST	Chlorpyrifos methyl	5598-13-0	2 µg/wipe	GC-ECD
PEST	Ethion	563-12-2	2 µg/wipe	GC-ECD
PEST	Parathion (Parathion-ethyl)	56-38-2	2 µg/wipe	GC-ECD
PEST	Chlordane	57-74-9	0.15 µg/wipe	GC-ECD
PEST	Lindane (gamma-BHC)	58-89-9	0.5 µg/wipe	GC-ECD
PEST	Dimethoate	60-51-5	5 µg/wipe	GC-ECD
PEST	Dieldrin	60-57-1	0.15 µg/wipe	GC-ECD
PEST	Dichlorvos	62-73-7	3 µg/wipe	GC-ECD
PEST	Endrin	72-20-8	0.3 µg/wipe	GC-ECD
PEST	Methoxychlor	72-43-5	1.5 µg/wipe	GC-ECD
PEST	p,p'-DDD	72-54-8	0.3 µg/wipe	GC-ECD
PEST	p,p'-DDE	72-55-9	0.15 µg/wipe	GC-ECD

Table D-1. Analytical Detection Limits (continued)

Class	Chemical Name	CASRN	Practical Quantitation Limits[a]	Analytical Technique[b]
PEST	Phosmet	732-11-6	3 µg/wipe	GC-ECD
PEST	Heptachlor	76-44-8	0.15 µg/wipe	GC-ECD
PEST	Toxaphene	8001-35-2	6 µg/wipe	GC-ECD
PEST	Pentachloronitrobenzene[d]	82-68-8	1 µg/wipe[d]	GC-ECD
PEST	Fonofos	944-22-9	2 µg/wipe	GC-ECD
PEST	Tetrachlorvinphos [iso][d]	961-11-5	3 µg/wipe[d]	GC-ECD
SVOC	4-Nitroaniline	100-01-6	20 µg/wipe	GC-MS
SVOC	Benzyl alcohol	100-51-6	20 µg/wipe	GC-MS
SVOC	2,4-Dimethylphenol	105-67-9	20 µg/wipe	GC-MS
SVOC	p-Cresol	106-44-5	20 µg/wipe	GC-MS
SVOC	1,4-Dichlorobenzene	106-46-7	20 µg/wipe	GC-MS
SVOC	4-Chloroaniline	106-47-8	20 µg/wipe	GC-MS
SVOC	Bis(2-chloro-1-methylethyl) ether[f]	108-60-1	20 µg/wipe	GC-MS
SVOC	Phenol	108-95-2	20 µg/wipe	GC-MS
SVOC	Bis(2-chloroethyl)ether	111-44-4	20 µg/wipe	GC-MS
SVOC	Bis(2-ethylhexyl)phthalate	117-81-7	20 µg/wipe	GC-MS
SVOC	Di-n-octyl phthalate	117-84-0	20 µg/wipe	GC-MS
SVOC	Anthracene	120-12-7	20 µg/wipe	GC-MS
SVOC	1,2,4-Trichlorobenzene	120-82-1	20 µg/wipe	GC-MS
SVOC	2,4-Dichlorophenol	120-83-2	20 µg/wipe	GC-MS
SVOC	Pyrene	129-00-0	20 µg/wipe	GC-MS
SVOC	Dibenzofuran	132-64-9	20 µg/wipe	GC-MS
SVOC	Indeno(1,2,3-cd)pyrene	193-39-5	20 µg/wipe	GC-MS
SVOC	Benz(b)fluoranthene	205-99-2	20 µg/wipe	GC-MS
SVOC	Fluoranthene	206-44-0	20 µg/wipe	GC-MS
SVOC	Benzo(k)fluoranthene	207-08-9	20 µg/wipe	GC-MS
SVOC	Chrysene	218-01-9	20 µg/wipe	GC-MS
SVOC	Benzo(a)pyrene	50-32-8	20 µg/wipe	GC-MS
SVOC	2,4-Dinitrophenol	51-28-5	20 µg/wipe	GC-MS
SVOC	4,6-Dinitro-o-cresol	534-52-1	20 µg/wipe	GC-MS
SVOC	Dibenzo(a,h)anthracene	53-70-3	20 µg/wipe	GC-MS
SVOC	1,3-Dichlorobenzene	541-73-1	20 µg/wipe	GC-MS
SVOC	Benz(a)anthracene	56-55-3	20 µg/wipe	GC-MS
SVOC	3-Methyl-4-chlorophenol	59-50-7	20 µg/wipe	GC-MS
SVOC	N-Nitrosodi-N-propylamine	621-64-7	20 µg/wipe	GC-MS
SVOC	N-Nitrosodimethylamine	62-75-9	20 µg/wipe	GC-MS
SVOC	Hexachloroethane	67-72-1	20 µg/wipe	GC-MS
SVOC	Hexachlorocyclopentadiene	77-47-4	20 µg/wipe	GC-MS
SVOC	Isophorone	78-59-1	20 µg/wipe	GC-MS
SVOC	Acenaphthene	83-32-9	20 µg/wipe	GC-MS

Table D-1. Analytical Detection Limits (continued)

Class	Chemical Name	CASRN	Practical Quantitation Limits[a]	Analytical Technique[b]
SVOC	Diethyl phthalate	84-66-2	20 µg/wipe	GC-MS
SVOC	Dibutyl phthalate	84-74-2	20 µg/wipe	GC-MS
SVOC	Butyl benzyl phthalate	85-68-7	20 µg/wipe	GC-MS
SVOC	N-nitrosodiphenylamine	86-30-6	20 µg/wipe	GC-MS
SVOC	Hexachloro-1,3-butadiene	87-68-3	20 µg/wipe	GC-MS
SVOC	2,4,6-Trichlorophenol	88-06-2	20 µg/wipe	GC-MS
SVOC	2-Nitroaniline	88-74-4	20 µg/wipe	GC-MS
SVOC	Naphthalene	91-20-3	20 µg/wipe	GC-MS
SVOC	2-Methylnaphthalene	91-57-6	20 µg/wipe	GC-MS
SVOC	2-Chloronaphthalene	91-58-7	20 µg/wipe	GC-MS
SVOC	o-Cresol	95-48-7	20 µg/wipe	GC-MS
SVOC	1,2-Dichlorobenzene	95-50-1	20 µg/wipe	GC-MS
SVOC	2-Chlorophenol	95-57-8	20 µg/wipe	GC-MS
SVOC	2,4,5-Trichlorophenol	95-95-4	20 µg/wipe	GC-MS
SVOC	3-Nitroaniline	99-09-2	20 µg/wipe	GC-MS

Notes:
[a]These are examples of PQLs or reporting limits (referred to in this TG as detection limits). Capable laboratories should be able to achieve these limits and may be able to validate/report lower PQLs (possibly only by request) if needed to meet SWSLs.
[b]The analytical technique listed was used to achieve the PQL listed; other techniques may be used as appropriate and if validated.
[c]Chemical can also be determined as an SVOC.
[d]There were no PQLs available for the surface wipes matrix; PQLs were projected based on a comparison of the chemical's PQL for other matrices to PQLs of other compounds in the same chemical class and for the same matrix.
[e]Based on the PQL for total chromium.
[f]bis (2-chloroisopropyl) ether often incorrectly listed as a synonym.

Legend:
µg/wipe = microgram per wipe
GC-FPD = gas chromatography-flame photometric detection
IC = ion chromatography
pg/wipe = picagrams per wipe
HRGC-HRMS = high resolution gas chromatography-high resolution mass spectrometry
GC-ECD = gas chromatography-electron capture detection
ICP = inductively coupled plasma (spectroscopy)
ICP-MS = inductively couple plasma-mass spectrometry
CVAA = cold vapor atomic absorption (spectroscopy)
GC-MS = gas chromatography-mass spectrometry

GLOSSARY

Section I
Acronyms and Abbreviations

ABS_d
dermal absorption fraction

ACGIH®
American Conference of Governmental Industrial Hygienists

ACH
air changes per hour

A_{cs}
contact surface area

AD/AED
aerodynamic diameter

ANL
Argonne National Laboratory

A_s
source area or contact surface area

ASHRAE
American Society of Heating, Refrigerating, and Air-Conditioning Engineers

AT
averaging time

BASE
Building Assessment Survey and Evaluation (USEPA)

BLS
Bureau of Labor Statistics

C
chemical concentration or chemical loading on surface

C_{air}
resuspended air concentration

Cal/EPA
Calfornia Environmental Protection Agency

CASRN
Chemical Abstracts Service Registry Number

CBECS
Commercial Building Energy Consumption Survey

CDC
Centers for Disease Control (and Prevention)

CDFA
California Department of Food and Agriculture

C_{ED}
total contaminant mass at the end of the exposure duration

CEPA
Canadian Environmental Protection Act

CFR
Code of Federal Regulations

CFU
colony-forming units

cm
centimeter

cm^2
square centimeter

cm^2/hr
square centimeters per hour

COPC
Contaminants of Potential Concern

C_s
contaminant surface loading or deposition

CSF
cancer slope factor

CSF_d
dermal cancer slope factor

CSF_{inh}
inhalation cancer slope factor

CSF_o
oral cancer slope factor

CSL
contaminant surface load (hard or soft)

CVAA
cold vapor atomic absorption (spectroscopy)

CWA
chemical warfare agent

C_{wipe}
surface wipe level

DAD
dermal absorbed dose

dC_{air}/dt
resuspended air concentration at time (concentration/time)

DEHE
Directorate of Environmental Health Engineering (USACHPPM)

DEPA
Danish Environmental Protection Agency

DHHS
(U.S.) Department of Health and Human Services

DL
detection limit

DOE
(U.S.) Department of Energy

EASE
Estimation and Assessment of Substance Exposure

ECAO
Environmental Criteria and Assessment Office (USEPA)

ED
exposure duration

EF
exposure frequency

EHRAP
Environmental Health Risk Assessment Program (USACHPPM)

EIA
Energy Information Administration

E_{mi}
dermal (or indirect ingestion) exposure based on microactivity approach

EP
exposure parameter

EV_{derm}
event frequency for estimating the dermal dose (events/day)

EV_{ing}
event frequency for estimating intake from incidental ingestion (events/day)

EXP
explosive

Fd
fraction of skin surface area that actually contacts the surface

FDA
(U.S.) Federal Drug Administration

F_f
fraction of exposed skin area that contacts the mouth

F_{hhi}
fraction of exposed skin area that contacts a hand-held item

F_m
fraction of hand-held item that contacts the mouth

FQPA
Food Quality Protection Act

f_{resp}
fraction respirable (or respirable fraction)

ft
feet

ft^2
square feet

FT_{hhi}
fraction of the exposed skin area that contacts the hand-held item

FT_{hi}
fraction of substance transferred from hands to item

FT_{im}
fraction of substance transferred from hand-held item to mouth

FT_{sm}
fraction of substance transferred from skin to mouth

FT_{ss}
fraction transferred from surface to the skin

FTU
fingertip unit

GC-ECD
gas chromatography-electron capture detection

GC-FPD
gas chromatography-flame photometric detection

GC-MS
gas chromatography-mass spectrometry

g/cm^3
gram per cubic centimeter

GI
gastrointestinal

g/m^2
grams per square meter

HERB
herbicide

hr
hour

HR
hazard ratio

HRGC-HRMS
high resolution gas chromatography-high resolution mass spectrometry

HUD
(U.S. Department of) Housing and Urban Development

HVAC
heating, ventilation, and air-conditioning

IAWG
Indoor Air Working Group

IC
ion chromatography

ICP
inductively coupled plasma (spectroscopy)

ICP-MS
inductively coupled plasma-mass spectrometry

IFMA
International Facility Management Association

IOM
Institute of Medicine

IR_{inh}
inhalation rate

IRIS
Integrated Risk Information System (USEPA)

ISR
indoor surface residue

K
resuspension factor

k
loss based on fraction transferred from the surface to the skin

kg
kilogram

kg/cm^2
kilogram per square centimeter

m^2
square meter

m^3
cubic meter

MADEP
Massachusetts Department of Environmental Protection

MET
metal

mg
milligram

mg/cm^2
milligram per square centimeter

mg/hr
milligram per hour

mg/kg
milligram per kilogram

mg/m^2
milligram per square meter

mm
millimeter

m/s
meters per second

NA
nonapplicable

NCEA
National Center for Environmental Assessment (USEPA)

NCP
National Contingency Plan (USEPA)

NERL
National Exposure Research Laboratory (USEPA)

ng
nanogram

ng/cm^2
nanograms per square centimeter

NIOSH
National Institute for Occupational Safety and Health

NIST
National Institute of Standards and Technology

NLPCB
non-liquid polychlorinated biphenyl

NYSDOH
New York State Department of Health

OHEA
Office of Health and Environmental Assessment (USEPA)

OSHA
Occupational Safety and Health Administration

PAH
polycyclic aromatic hydrocarbons

PCB
polychlorinated biphenyl

PD_{derm}
potential dermal dose

PD_{ing}
potential dose from incidental ingestion

PEST
pesticide

pg/wipe
picagram per wipe

PHED
Pesticide Handlers Exposure Database

PM
particulate matter

PPRTV
Provisional Peer-Reviewed Toxicity Values

PQL
practical quantitation limit

PRG
preliminary remediation goal

R
resuspension rate

RfC
reference concentration

RfD
reference dose

RME
reasonable maximum exposure

SA
surface area

SD
standard deviation

SERPACWA
Skin Exposure Reduction Paste Against Chemical Warfare Agents

SOP
standing (or standard) operating procedure

SVOC
semi-volatile organic compound

SWSL
surface wipe screening level

TC
transfer coefficient

TCDD
2,3,7,8-Tetrachlorodibenzo-p-dioxin

TE
transfer efficiency

TEF
toxicity equivalency factor

TG
technical guide

THI
target hazard index

THR
target hazard ratio

TL
target level

TR
target risk

TSCA
Toxic Substances Control Act

UR
unit risk

USACHPPM
U.S. Army Center for Health Promotion and Preventive Medicine

USEPA
U.S. Environmental Protection Agency

V
room volume

V_{dep}
deposition velocity

VOC
volatile organic compound

WHO
World Health Organization

WSDOH
Washington State Department of Health

WTC
World Trade Center

w/w
weight in weight

°C
degrees Celsius

µg
microgram

µg/cm^2
microgram per square centimeter

µg/m^2
microgram per square meter

µg/m^3
microgram per cubic meter

µg/dL
microgram per deciliter

µg/ft^2
microgram per square foot

µg/m^2
microgram per square meter

µg/wipe
microgram per wipe

µm
micrometer

η
surface wipe removal efficiency

λ_a
air exchange rate

λ_{dep}
deposition loss rate

Local Reproduction is Authorized and Encouraged

June 2009

TG 312

Risk Assessment Methods for Surface Wipe Data