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Risk Assessment Guidance for Superfund
Volume I: Human Health
Evaluation Manual
(Part E, Supplemental Guidance for Dermal Risk Assessment)

Final

Office of Superfund Remediation and Technology Innovation
U.S. Environmental Protection Agency
Washington, DC

This document provides guidance to EPA Regions concerning how the Agency intends to exercise its discretion in implementing one aspect of the CERCLA remedy selection process. The guidance is designed to implement national policy on these issues.

Some of the statutory provisions described in this document contain legally binding requirements. However, this document does not substitute for those provisions or regulations, nor is it a regulation itself. Thus, it cannot impose legally-binding requirements on EPA, states, or the regulated community, and may not apply to a particular situation based upon the circumstances. Any decisions regarding a particular remedy selection decision will be made based on the statute and regulations, and EPA decisionmakers retain the discretion to adopt approaches on a case-by-case basis that differ from this guidance where appropriate. EPA may change this guidance in the future.

ABOUT THIS DOCUMENT

WHAT IT IS

This document is Supplemental Guidance (Part E) to the *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (RAGS)*. This document incorporates and updates the principles of the EPA interim report, *Dermal Exposure Assessment: Principles and Applications* (DEA) (U.S. EPA, 1992a), released by the Office of Health and Environmental Assessment (OHEA), in the Office of Research and Development (ORD), in January 1992. Part E contains methods for conducting dermal risk assessments. EPA has found these methods generally to be appropriate. However, for each dermal risk assessment, Regions must decide whether these methods, or others, are appropriate, depending on the facts. Specific information and data tables and updated or modified assumptions or variables used in this guidance are available on the following EPA WebPages:

http://www.epa.gov/oswer/riskassessment/
or
http://www.epa.gov/superfund/programs/risk/ragse/index.htm

FOR WHOM

This guidance document is for risk assessors, risk assessment reviewers, remedial project managers (RPMs), and risk managers involved in Superfund site investigations and human health risk assessments.

WHAT IS NEW

RAGS Part E updates or expands the following elements in dermal risk assessment methodology:

- updated dermal exposure assessment equations for the water pathway
- updated table for screening contaminants of potential concern (COPCs) from contaminants in water
- specific dermal absorption from soil values for ten chemicals and recommended defaults for screening other organic compounds
- updated soil adherence values based on receptor activities
- updated dermal exposure parameters that are consistent with the *Exposure Factors Handbook* (U.S. EPA, 1997a)
- an expanded Uncertainty Analysis section that discusses and compares the contribution of specific components to the overall uncertainty in a dermal risk assessment.

REVIEW

This guidance document has been reviewed by internal EPA peer review (May 1997), external peer review (January 1998), and followup external peer review (January 2000). In addition, specific technical recommendations were provided by a Peer Consultation Workshop organized by the Risk Assessment Forum (December 1998). EPA received public comments on the draft of the guidance that was released in December 2001.

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[1] In 2003, The EPA Office of Solid Waste and Emergency Response (OSWER) reorganized. Many of the functions and responsibilities of the Office of Emergency and Remedial Response (OERR), including coordinating the development of this guidance, were assigned to the Office of Superfund Remediation and Technology Innovation (OSRTI).

PREFACE

This guidance is the fifth part (Part E) in the series *Risk Assessment Guidance for Superfund: Volume I - Human Health Evaluation Manual* (RAGS/HHEM) (U.S. EPA, 1989). Part A of this guidance describes how to conduct a site-specific baseline risk assessment. Part B provides guidance for calculating risk-based concentrations that may be used, along with applicable or relevant and appropriate requirements (ARARs) and other information, to develop preliminary remediation goals (PRGs) during project scoping. PRGs and final remediation levels can be used throughout the analyses in Part C to assist in evaluating the human health risks of remedial alternatives. Part D complements the guidance provided in Parts A, B and C and presents approaches to standardizing risk assessment planning, reporting and review. Part E is intended to provide a consistent methodology for assessing the dermal pathway for Superfund human health risk assessments. It incorporates and updates principles of the EPA interim report, *Dermal Exposure Assessment: Principles and Applications* (U.S. EPA, 1992a).

Several appendices are included in this guidance to support the summary calculations presented in the main body of the document (Appendix A), to provide physical constants for specific chemicals (Appendix B), and to provide tables for screening chemicals for the pathway (Appendix C). Appendix D provides sample calculations.

ACRONYMS/ABBREVIATIONS

Acronym/ Abbreviation	Definition
a, b, c	Correlation coefficients which have been fitted to the Flynn's data to give Equation 3.8
ABS	Dermal absorption from soil
ABS_d	Fraction of contaminant absorbed dermally (dimensionless)
ABS_{GI}	Fraction of contaminant absorbed in gastrointestinal tract (dimensionless)
AF	Adherence factor of soil to skin (mg/cm^2-event)
ARARs	Applicable or Relevant and Appropriate Requirements
AT	Averaging time (days)
β	Constant specific for the medium through which diffusion is occurring
B	Dimensionless ratio of the permeability coefficient of a compound through the stratum corneum relative to its permeability coefficient across the viable epidermis (dimensionless)
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
BW	Body weight (kg)
CF	Conversion factor (10^{-6} kg/mg)
COC	Contaminant of Concern
COPC	Contaminant of Potential Concern
cPAH	Carcinogenic polynuclear aromatic hydrocarbons
C_{soil}	Chemical concentration in soil (mg/kg)
C_{tot}	Total concentration of chemical in the aqueous solution (mg/l)
C_u	Concentration of the non-ionized species (mg/l)
C_w	Chemical concentration in water (mg/cm^3)
DA_{event}	Absorbed dose per event (mg/cm^2-event)
DAD	Dermal absorbed dose (mg/kg-day)
D_e	Effective diffusivity of the absorbing chemical in the epidermis (cm^2/hr)
D_o	Diffusivity of a hypothetical molecule with a molecular volume (MV) = 0 (cm^2/hr)
D_{sc}	Effective diffusion coefficient of the chemical through the stratum corneum
DEA	Dermal Exposure Assessment: Principles and Applications (U.S. EPA, 1992a)
ED	Exposure duration (years)
EF	Exposure frequency (days/year)

ACRONYMS/ABBREVIATIONS (continued)

Acronym/ Abbreviation	Definition
EFH	Exposure Factors Handbook (U.S. EPA, 1997a)
EPA	U. S. Environmental Protection Agency
EPC	Exposure point concentration
EPD	Effective Prediction Domain
EV	Event frequency (events/day)
FA	Fraction absorbed water (dimensionless)
FTSA	Fraction of total surface area for the specified body part
GI	Gastrointestinal
GSD	Geometric standard deviation
HHEM	Human Health Evaluation Manual
IR	Ingestion rate (for water, liters/day)
K_{ew}	Equilibrium partition coefficient between the epidermis and water for the absorbing chemical (dimensionless)
K_{ow}	Octanol/water partition coefficient (dimensionless)
K_p	Dermal permeability coefficient of compound in water (cm/hr)
$K_{p\text{-}msd}$	Measured dermal permeability coefficient of compound in water (cm/hr)
$K_{p\text{-}pred}$	Predicted dermal permeability coefficient of compound in water (cm/hr)
$K_{p,ve}$	Steady-state permeability coefficient through the viable epidermis (ve) (cm/hr)
$K_{sc/w}$	Equilibrium partition coefficient between the stratum corneum and water (chemical specific dimensionless)
L_e	Effective thickness of the epidermis (cm)
l_{sc}	Apparent thickness of stratum corneum (cm)
MV	Molar volume (cm^3/mole)
MW	Molecular weight (g/mole)
IRIS	Integrated Risk Information System
NCEA	National Center for Environmental Assessment
OERR	Office of Emergency and Remedial Response (now known as OSRTI)
OHEA	Office of Health and Environmental Assessment

ACRONYMS/ABBREVIATIONS (continued)

Acronym/ Abbreviation	Definition
ORD	Office of Research and Development
OSWER	Office of Solid Waste and Emergency Response
OSRTI	Office of Superfund Remediation and Technology Innovation
$P_{particle}$	Particle density (g/cm^3)
PAH	Polynuclear aromatic hydrocarbon
PCBs	Polychlorinated biphenyls
pK_a	Chemical specific ionization constant
PRG	Preliminary Remediation Goals
RAGS	Risk Assessment Guidance for Superfund (U.S. EPA, 1989)
RfD	Reference dose
RfD_{abs}	Absorbed reference dose (mg/kg-day)
RfD_o	Reference dose oral (mg/kg-day)
RME	Reasonable maximum exposure
SA	Skin surface area available for contact (cm^2)
SC	Stratum corneum
SCS	Soil Conservation Service
SEE	Standard error of the estimator
SF	Slope factor
SF_{abs}	Absorbed slope factor $(mg/kg\text{-}day)^{-1}$
SF_o	Oral slope factor $(mg/kg\text{-}day)^{-1}$
SF_d	Dermal cancer slope factor $(mg/kg\text{-}day)^{-1}$
SFS_{adj}	Age-adjusted dermal exposure factor (mg-yrs/kg-event)
SVOCs	Semivolatile organic compounds
TCDD	Tetrachlorodibenzo-p-dioxin
τ_{event}	Lag time per event (hr/event)
t^*	Time to reach steady-state (hr)
t_{event}	Event duration (hr/event)
THQ	Target Hazard Quotient (non-cancer)
TRL	Target Risk Level (cancer)

ACRONYMS/ABBREVIATIONS (continued)

Acronym/ Abbreviation	Definition
t_{sc}	Turnover time for the stratum corneum (days)
95% CL	95% confidence level
95% LCL	95% lower confidence level
95% UCL	95% upper confidence level

CHAPTER 1

INTRODUCTION AND FLOWCHART

1.1 INTRODUCTION

This guidance is the fifth part (Part E) in the series *Risk Assessment Guidance for Superfund: Volume I - Human Health Evaluation Manual* (RAGS/HHEM) (U.S. EPA, 1989). Part A of this guidance describes how to conduct a site-specific baseline risk assessment. Part B provides guidance for calculating risk-based concentrations that may be used, along with applicable or relevant and appropriate requirements (ARARs) and other information, to develop preliminary remediation goals (PRGs) during project scoping. PRGs and final remediation levels can be used throughout the analyses in Part C to assist in evaluating the human health risks of remedial alternatives. Part D complements the guidance provided in Parts A, B and C and presents approaches to standardizing risk assessment planning, reporting and review. Part E is intended to provide a consistent methodology for assessing the dermal pathway for Superfund human health risk assessments. Part E incorporates and updates principles of the EPA interim report, *Dermal Exposure Assessment: Principles and Applications* (DEA) (U.S. EPA, 1992a). The DEA is considered guidance for all EPA environmental programs. Exhibit 1-1 illustrates the correspondence of RAGS/HHEM activities with the steps in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remedial process.

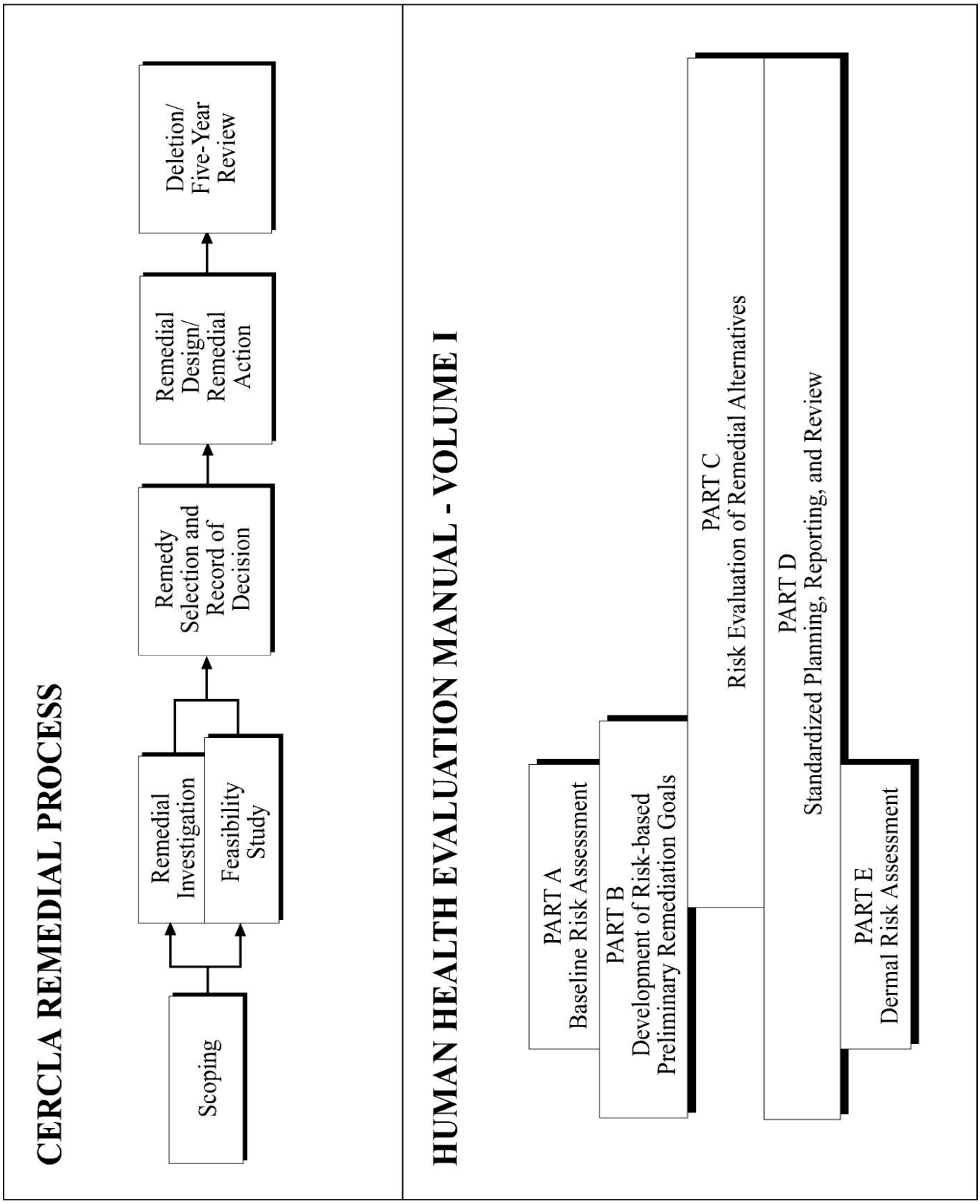
In January 1992, the Office of Health and Environmental Assessment (OHEA), in the Office of Research and Development (ORD) of the U.S. Environmental Protection Agency (EPA) issued an interim report, *Dermal Exposure Assessment: Principles and Applications* (U.S. EPA, 1992a). The 1992 ORD document, from now on referred to as DEA, provided guidance for conducting dermal exposure assessments. The conclusions of the DEA were summarized at the National Superfund Risk Assessors Conference in January 1992 when regional risk assessors requested that a workgroup be formed to prepare an interim dermal risk assessment guidance for the Superfund program based on the DEA. The Part E guidance serves to promote consistency in procedures used by the Regions to assess dermal exposure pathways at Superfund sites. In August 1992, a draft Superfund Interim Dermal Risk Assessment Guidance document was circulated for comment but was never issued as an Office of Solid Waste and Emergency Response (OSWER) Directive. This current guidance supersedes the 1992 Superfund document.

This 2002 Superfund RAGS Part E, Interim Supplemental Guidance for Dermal Risk Assessment (from now on referred to as RAGS Part E) is the result of Superfund Dermal Workgroup meetings from FY 95 through FY 00 on issues associated with the characterization of risk resulting from the dermal exposure pathway. RAGS Part E updates the recommendations presented in the DEA, the updated *Exposure Factors Handbook* (U.S. EPA, 1997a), and additional information from literature as cited. Users of this guidance are strongly encouraged to review and understand the material presented in the DEA. This guidance is considered interim, pending release of any update to the DEA from ORD. As more data become available, RAGS Part E may be updated.

It should be noted that this document limits its guidance on dermal exposure assessment to the discussion of systemic chronic health effects resulting from low-dose, long-term exposure. However, acute chemical injury to the skin should also be examined to present an accurate and comprehensive assessment of toxicity through the dermal route. The potential for direct dermal contact resulting in dermal effects such as allergic contact responses, urticarial reactions, hyperpigmentation, and skin cancer should be discussed qualitatively in the exposure section of the risk assessment.

This document does not provide guidance on quantifying dermal absorption of chemicals resulting from exposure to vapors. The Superfund Dermal Workgroup agreed with the finding in the DEA report that many chemicals, with low vapor pressure and low environmental concentrations, cannot achieve adequate vapor concentration to pose a dermal exposure hazard.

EXHIBIT 1-1
RELATIONSHIP OF THE HUMAN HEALTH EVALUATION TO THE CERCLA PROCESS



For chemicals with the potential to achieve adequate vapor concentrations, this guidance assumes that they are primarily absorbed through the respiratory tract. Additional information on dermal absorption of chemical vapors can be found in the DEA, Chapter 7.

1.2 ORGANIZATION OF DOCUMENT

This guidance is structured to be consistent with the four steps of the Superfund risk assessment process: hazard identification, exposure assessment, toxicity assessment, and risk characterization. Chapters 2.0 - 5.0 of RAGS Part E follow these steps:

Chapter 2: Hazard Identification– identifies those chemicals that make a significant contribution to exposure and risk at a Superfund site.

Chapter 3: Exposure Assessment– evaluates the pathways by which individuals could be exposed to chemicals present at a Superfund site.

Chapter 4: Toxicity Assessment– identifies the potential adverse health effects associated with the contaminants of concern identified at the site.

Chapter 5: Risk Characterization– incorporates information from the three previous chapters to evaluate the potential risk to exposed individuals at the site. This chapter also contains a discussion of the uncertainties associated with estimating risk for the dermal pathway.

Chapter 6: Summary and Recommendations– provides a summary of the main points for each step in the dermal risk assessment process and recommendations for future data needs to improve the evaluation of dermal exposures.

1.3 FLOWCHARTS

The following flowcharts (Exhibit 1-2 and Exhibit 1-3) facilitate the process of performing a dermal risk assessment, by identifying the key steps and the locations of specific information. Separate flowcharts are provided for the water and the soil pathways. Descriptions of the processes illustrated in both flowcharts follow.

Dermal Risk Assessment Process for Water Pathway – The screening process illustrated in Exhibit 1-2 identifies those chemicals that should be evaluated for the dermal pathway. The process identifies those chemicals where the dermal pathway has been estimated to contribute more than 10% of the oral pathway, using conservative residential exposure criteria. Screening tables in Appendix B (Exhibit B-3 for organics and Exhibit B-4 for inorganics) help provide a recommendation as to whether the dermal pathway should be evaluated for a given chemical. If so, the next step is to determine the rate of migration of the chemical through the skin, using the dermal permeability coefficient (K_p), derived from either experimentally measured or predicted values. If default residential exposure assumptions are appropriate for the risk assessment, then the absorbed dose, DA_{event} term, can be extracted from either Exhibit B-3 or B-4, and used with the chemical concentration to calculate the dermally absorbed dose (DAD) term. If default residential exposure assumptions are not appropriate, references to the specific equations and information sources are provided in the Exhibit 1-2 flowchart. Finally, the procedures for the toxicity assessment and risk characterization steps are also outlined.

Dermal Risk Assessment Process for Soil Pathway – There is no screening process for eliminating chemicals in a soil matrix from a dermal risk assessment, as there is for the water pathway. The first step in the hazard identification process illustrated in Exhibit 1-3 is to determine if quantitative dermal absorption from soil (ABS) values are available for the chemical to be evaluated. If not, the decision whether or not to use default values as surrogates for those chemicals without specific recommended values must be made. If data are available, a site-specific ABS value could be used. Section 3.0, Exposure Assessment, summarizes exposure parameter values for a reasonable maximum exposure (RME) exposure scenario as well as activity-specific values. The steps in the toxicity assessment and risk characterization are the same for both the soil and water pathways.

Exhibit 1-2 WATER PATHWAY

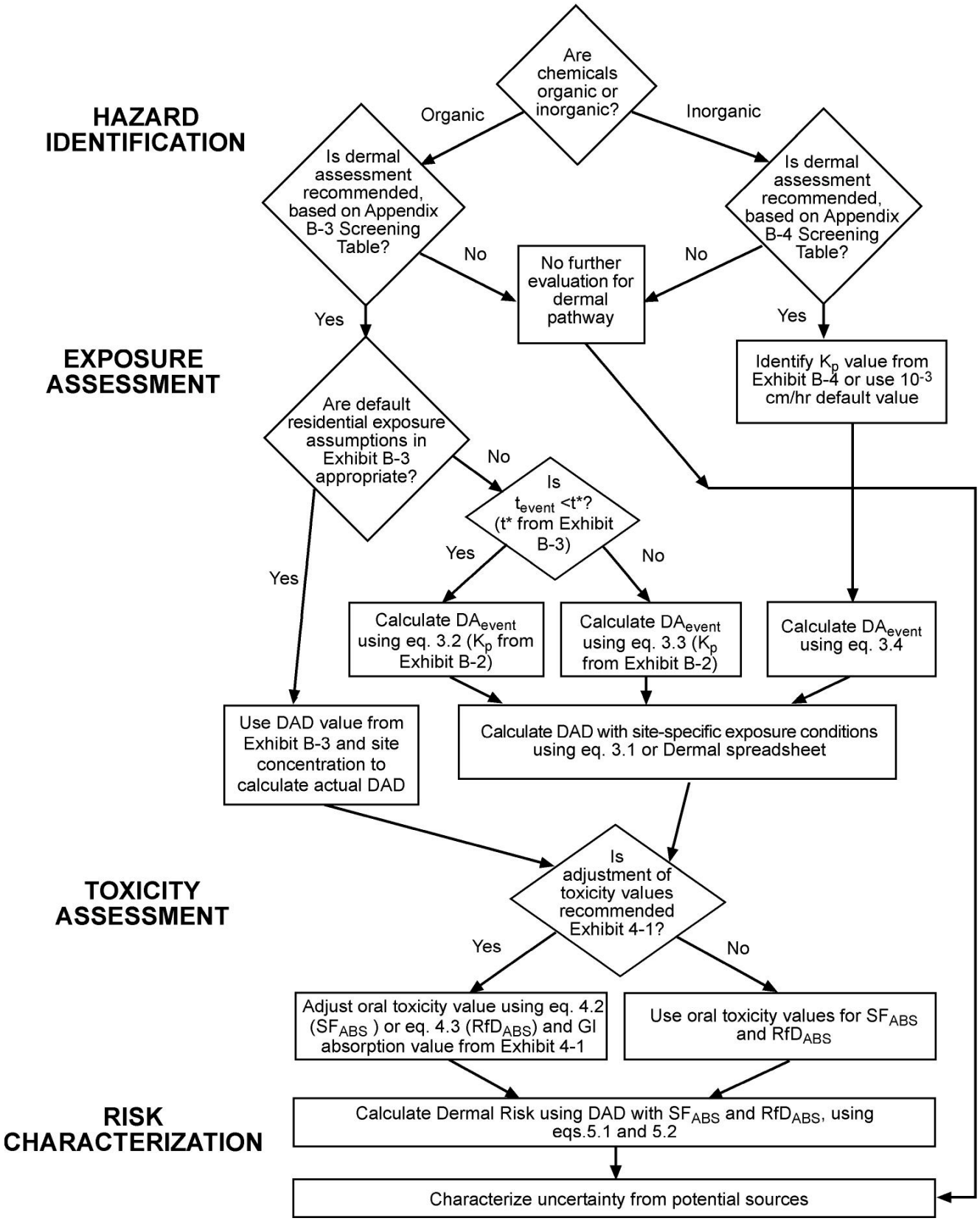
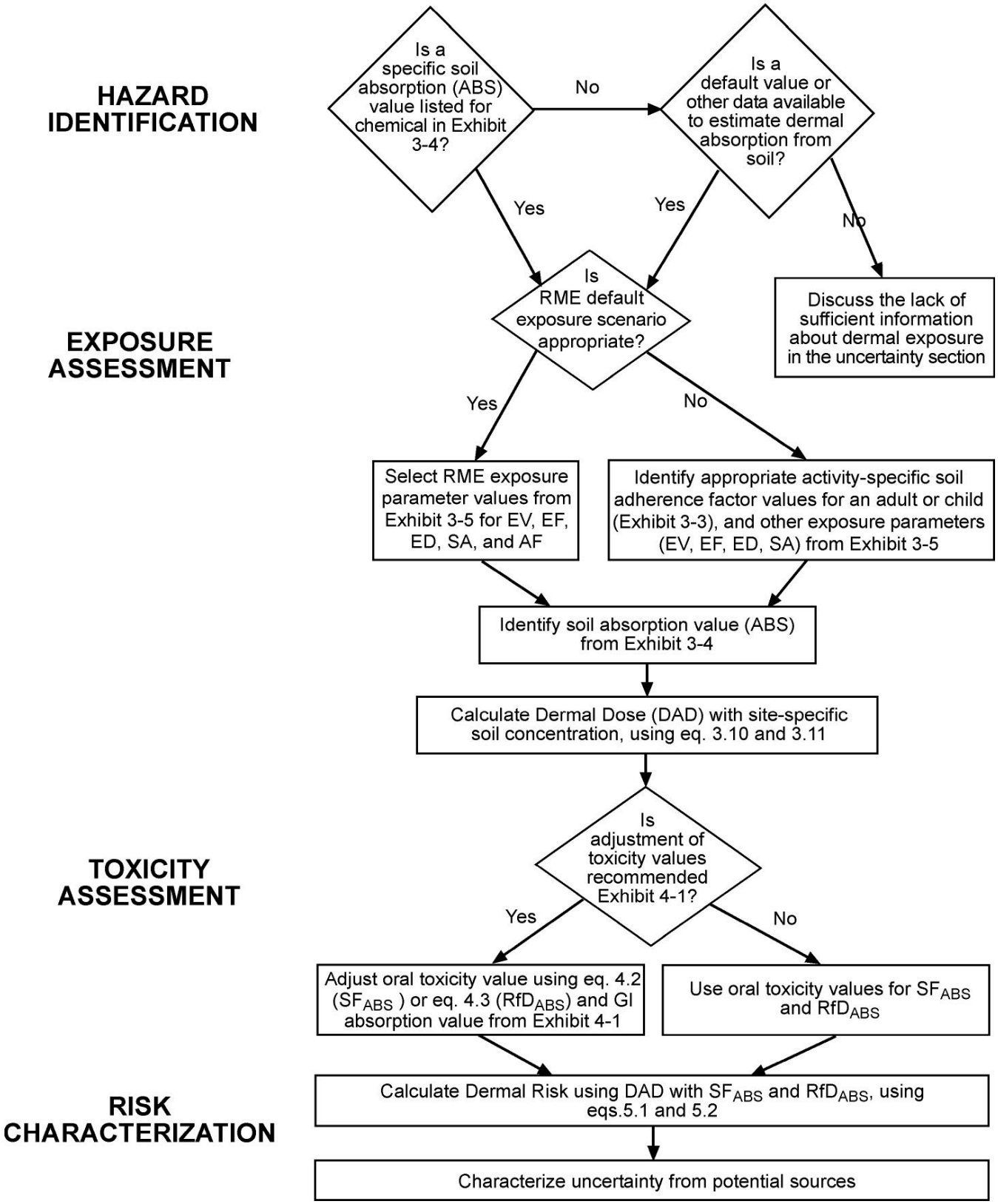


Exhibit 1-3 SOIL PATHWAY



CHAPTER 2

HAZARD IDENTIFICATION

The hazard identification step identifies those chemicals that contribute to the majority of exposure and risk at a Superfund site. The "contaminants of potential concern" (COPCs) are chemicals chosen because of their occurrence, distribution, fate, mobility and persistence in the environment. Each chemical's concentration and toxicity are also considered. Algorithms, permeability constants and other parameter values presented in this guidance supersede the dermal methodology provided in DEA and the *Risk Assessment Guidance for Superfund* (RAGS, U.S. EPA, 1989).

2.1 CHOOSING CONTAMINANTS OF CONCERN FOR THE DERMAL-WATER PATHWAY

Consideration of the dermal exposure pathway is important in scoping and planning an exposure and risk assessment. The assessor should decide the level (from cursory to detailed) of analysis needed to make this decision. The screening procedure in Section A.4 of Appendix A analyzes whether or not the dermal exposure route is likely to be significant compared to the other routes of exposure. This discussion is based on the DEA methodology, Chapter 9, using parameters provided in this guidance. Readers are encouraged to consult the DEA document for more details. The screening procedure in Section A.4 is intended to focus attention on specific chemicals that may be important for dermal exposure and is provided for the convenience of the risk assessor. However, risk assessors may decide not to use the screening and proceed to a quantitative assessment of all chemicals at a site.

Exhibits B-3 and B-4 in Appendix B provide the results of applying the Appendix A screening procedure to identify organic and inorganic chemicals that contribute significantly to the risk for the dermal route at a site. For this guidance, the Superfund Dermal Workgroup decided that the dermal route is significant if it contributes at least 10% of the exposure derived from the oral pathway. These results are based upon comparing two main household daily uses of water: as a source for drinking and for showering or bathing. This screening procedure is therefore limited to residential exposure scenarios where both ingestion and showering/bathing are considered in the site risk assessment. The screening procedure does not consider swimming exposures, and thus should not be used for screening chemicals in surface water where exposure may be through swimming activity. However, if swimming is an actual or potential exposure scenario in the site risk assessment, dermal exposure should be quantitatively evaluated, using input parameters described in the document.

Note that the results of this screening procedure are the actual results of a quantitative exposure assessment for these two routes of exposure. All calculations needed for the evaluation of DAD for water, as described in Chapter 3 and in Appendices A and B, were performed for the list of chemicals presented in Exhibit B-3 and Exhibit B-4, using the exposure conditions specified in each exhibit. These exhibits are provided as a screening tool for risk assessors to focus the dermal risk assessment on those chemicals that are more likely to make a contribution to the overall risk.

The example screening results are provided in two columns in Exhibit B-3 and Exhibit B-4: the column labeled "Derm/Oral" gives the actual ratio of the dermal exposure route as compared to the ingestion route (two liters of drinking water), and the column labeled "Chem Assess" gives the result of the comparison as a Y (Yes) or N (No) using the 10% criterion discussed above. When these default exposure assumptions are not appropriate, stepwise instructions are provided in Chapter 3 and Appendix B to incorporate site-specific exposure parameters.

2.2 CHOOSING CONTAMINANTS OF CONCERN FOR THE DERMAL-SOIL PATHWAY

The number of contaminants evaluated in the risk assessment for the dermal-soil pathway will be limited by the availability of dermal absorption values for chemicals in soil. Very limited data exist in the

literature for the dermal absorption of chemicals from soil. Chapter 3 provides recommended dermal absorption factors for ten chemicals in soil based on well-designed studies. If a detected compound does not have a dermal absorption value presented in Chapter 3, other sources of information, such as new exposure studies presented in the peer reviewed literature or site-specific in vitro and in vivo studies, may be considered to estimate a dermal absorption value. The EPA risk assessor should be consulted before conducting site-specific dermal absorption studies, to ensure that a scientifically sound study is developed and approved by the Agency.

CHAPTER 3

EXPOSURE ASSESSMENT

The exposure assessment evaluates the type and magnitude of exposures to chemicals of potential concern at a site. The exposure assessment considers the source from which a chemical is released to the environment, the pathways by which chemicals are transported through the environmental medium, and the routes by which individuals are exposed. Parameters necessary to quantitatively evaluate dermal exposures, such as permeability coefficients, soil absorption factors, body surface area exposed, and soil adherence factors are developed in the exposure assessment. In this chapter, the dermal assessment is evaluated for two exposure media: water (Section 3.1) and soil (Section 3.2).

EPA's *Policy for Risk Characterization* (U.S. EPA, 1995a) states that each Agency risk assessment should present information on a range of exposures (e.g., provide a description of risks to individuals in average and high end portions of the exposure distribution). Generally, within the Superfund program, to estimate exposure to an average individual (i.e., a central tendency), the 95% upper confidence limit (UCL) on the arithmetic mean is chosen for the exposure point concentration, and central estimates (i.e., arithmetic average, 50th percentile, median) are chosen for all other exposure parameters. This guidance document provides recommended central tendency values for dermal exposure parameters, using updated information from the *Exposure Factors Handbook* (EFH) (U.S. EPA, 1997a).

In comparison with the average exposure, the "high end" exposure estimate is defined as the highest exposure that is reasonably expected to occur at a site but that is still within the range of possible exposures, referred to as the reasonable maximum exposure (RME) (U.S. EPA, 1989). According to the *Guidance on Risk Characterization for Risk Managers and Risk Assessors* (U.S. EPA, 1992b), risk assessors should approach the estimation of the RME by identifying the most sensitive exposure parameters. The sensitivity of a parameter generally refers to its impact on the exposure estimates, which correlates with the degree of variability of the parameter values. Parameters with a high degree of variability in the distribution of parameter values are likely to have a greater impact on the range of risk estimates than those with low variability. For one or a few of the sensitive parameters, the maximum or near-maximum values should be used, with central tendency or average values used for all other parameters. The high-end estimates are based, in some cases, on statistically based criteria (95th or 90th percentiles), and in others, on best professional judgment. In general, exposure duration, exposure frequency, and contact rate are likely to be the most sensitive parameters in an exposure assessment (U.S. EPA, 1989). In addition, for the dermal exposure route, the soil adherence factor term is also a very sensitive parameter. This guidance provides recommended upper end estimates for individual exposure parameters and a recommended RME exposure scenario for residential and industrial settings, using updated information from the EFH and other literature sources.

3.1 ESTIMATION OF DERMAL EXPOSURES TO CHEMICALS IN WATER

3.1.1 STANDARD EQUATION FOR DERMAL CONTACT WITH CHEMICALS IN WATER

The same mathematical model for dermal absorption recommended in DEA is used here. The skin is assumed to be composed of two main layers, the stratum corneum and the viable epidermis, with the stratum corneum as the main barrier. A two-compartment distributed model was developed to describe the absorption of chemicals from water through the skin as a function of both the thickness of the stratum corneum (l_{sc}) and the event duration (t_{event}). The mathematical representation of the mass balance equation follows Fick's second law and is a partial differential equation with concentration as a function of both time and distance. The exact solution of this model is approximated by two algebraic equations: (1) to describe the absorption process when the chemical is only in the stratum corneum, i.e., non-steady state,

where absorption is a function of $t_{event}^{1/2}$; and (2) to describe the absorption process as a function of t_{event}, once steady state is reached. One fundamental assumption of this model is that absorption continues long after the exposure has ended, i.e., the final absorbed dose (DA_{event}) is estimated to be the total dose dissolved in the skin at the end of the exposure. For highly lipophilic chemicals or for chemicals that are not highly lipophilic but exhibit a long lag time (τ_{event}), some of the chemical dissolved into skin may be lost due to desquamation during that absorption period. A fraction absorbed term (FA) is included in the evaluation of DA_{event} to account for this loss of chemical due to desquamation. As shown in Appendix A, for normal desquamation rates to completely replace the stratum corneum in about 14 days, only chemicals with $\log K_{ow} > 3.5$ or chemicals with $t_{event} > 10$ hours (at any $\log K_{ow}$) would be affected by this loss.

The following procedures represent updates from the DEA and are recommended for the estimation of the dermal absorbed dose (DAD):

For Organics:

- The equation for DA_{event} is updated to include the net fraction available for absorption in the stratum corneum after exposure has ended (FA).

- The equation for the permeability coefficient (K_p) is updated by excluding three data points from the Flynn data base (Flynn, 1990) in the development of the correlation equation for K_p. The 95% confidence intervals are also provided for the estimation of K_p using this correlation equation.

- The screening procedures are updated to include the new values for K_p and FA in order to provide guidance when the dermal route would pose more than 10% of the ingested dose.

- A statistical analysis of the correlation equation for K_p provides the ranges of the octanol-water partition coefficient ($\log K_{ow}$) and molecular weight (MW) where the extrapolation of the K_p correlation equation would be valid.

- A discussion of the model validation and uncertainties related to the dermal absorption model for chemicals in water is included.

- Appendix A gives a detailed discussion of the above changes.

- The spreadsheet ORG04_01.XLS and Exhibits B-1 through B-3 of Appendix B provide the calculations of the dermal absorbed dose for over 200 organic chemicals, using a default exposure scenario.

For Inorganics:

- The measured values of the permeability coefficients for available chemicals are updated based on the latest literature.

- Screening procedures for determining when the dermal route would pose more than 10% of the ingested dose are updated to include the relative fraction absorbed by accounting for the actual gastrointestinal absorption (ABS_{GI}) of inorganics.

- Appendix A gives a detailed discussion of the above changes.

- The spreadsheet INORG04_01.XLS and Exhibit B-4 of Appendix B provide the calculations for the inorganics with available measured K_p or ABS_{GI}.

For chemicals in water, Equations 3.1, 3.2, 3.3 and 3.4 are used to evaluate the dermal absorbed dose. The following discussion summarizes the key steps in the procedure detailed in Appendix A.

For short exposure durations to organic chemicals in water (Equation 3.2), DA_{event} is not a function of the parameter B, which measures the ratio of the permeability coefficient of the chemical in the stratum corneum to its permeability coefficient in the viable epidermis, because neither the viable epidermis nor the cutaneous blood flow will limit dermal absorption during such short exposure durations.

For long exposure times, Equation 3.3 should be used to estimate DA_{event} for organic chemicals. The lag time is decreased because the skin has a limited capacity to reduce the transport rate of inorganic and/or highly ionized organic chemicals. In addition, the viable epidermis will contribute insignificantly as a barrier to these chemicals. Consequently, for inorganic and highly ionized organic chemicals, it is appropriate

Dermal Absorbed Dose – Water Contact

$$DAD = \frac{DA_{event} \times EV \times ED \times EF \times SA}{BW \times AT} \quad (3.1)$$

where:

Parameter		Definition (units)	Default Value
DAD	=	Dermally Absorbed Dose (mg/kg-day)	–
DA_{event}	=	Absorbed dose per event (mg/cm^2-event)	Chemical-specific, see Eq. 3.2, 3.3 and 3.4
SA	=	Skin surface area availablefor contact (cm^2)	See Exhibit 3-2
EV	=	Event frequency (events/day)	See Exhibit 3-2
EF	=	Exposure frequency (days/year)	See Exhibit 3-2
ED	=	Exposure duration (years)	See Exhibit 3-2
BW	=	Body weight (kg)	70 kg (adult) 15 kg (child)
AT	=	Averaging time (days)	noncarcinogenic effects AT = ED x 365 d/yr carcinogenic effects AT = 70 yr x 365 d/yr

to assume that τ_{event} and B are both near zero, which simplifies Equation 3.3 to Equation 3.4.

Discussions of the permeability coefficient (K_p) and all other parameters for water media are found in Section 3.1.2, with more details and data in Appendix A. Descriptions of the dermal absorption model and equations for calculating all the parameters to evaluate the dermal absorbed dose for organics (DA_{event} in Equations 3.3 and 3.4) are provided in Appendix A.1, and for inorganics (DA_{event} in Equation 3.4) in Appendix A.2. Appendix B (Exhibits B-3 and B-4) contains chemical-specific DA_{event} and DAD values per unit concentration, using default assumptions. Instructions for calculating DA_{event} and DAD values with site-specific exposure assumptions are provided (see Appendix A.5), and the spreadsheets (ORG04_01.XLS and INORG04_01.XLS), including all the calculations, will be available at http://www.epa.gov/oswer/ riskassessment/ or http://www.epa.gov/superfund/ programs/risk/ ragse/index.htm.

3.1.2 EXPOSURE PARAMETERS

3.1.2.1 Permeability Coefficient for Compounds in Water (K_p in cm/hr)

Some discussion of criteria for selecting an experimental K_p was presented in DEA, Chapter 5. The procedure recommended by RAGS Part E to estimate the permeability coefficient (K_p) of a compound is obtained from updating the correlation presented in DEA. Three data points which came from in vivo studies (ethyl benzene, styrene and toluene) from the Flynn database are now excluded in the development of the new K_p correlation, limiting its representation to in vitro studies using human skin. Updated K_p values for over two hundred common organic compounds in water are provided, in Appendix B, as estimated using procedures described below. It is recommended that these K_p values be used in Equations 3.2 and 3.3. K_p values for several inorganic compounds are given, and default permeability constants for all other inorganic compounds are provided in Exhibit 3-1, to be used in Equation 3.4.

Organics. The permeability coefficient is a function of the path length of chemical diffusion (defined here as stratum corneum thickness, l_{sc}), the membrane/vehicle partition coefficient of the chemical (here as octanol/water partition coefficient K_{ow} of the chemical), and the effective diffusion coefficient (D_{sc}) of the chemical in the stratum corneum, and can be written for a simple isotropic membrane as presented in Equations 3.5 and 3.6.

In this approach, K_p from Equation 3.7 is estimated via an empirical correlation as a function of K_{ow} and

Dermal Absorbed Dose per event for Organic Compounds – Water Contact

DA_{event} (mg/cm^2-event) is calculated for organic compounds as follows :

$$If\ t_{event} \le t^*,\ then:\ DA_{event} = 2\ FA \times K_p \times C_w \sqrt{\frac{6\ \tau_{event} \times t_{event}}{\pi}} \tag{3.2}$$

$$If\ t_{event} > t^*,\ then:\ DA_{event} = FA \times K_p \times C_w \left[\frac{t_{event}}{1 + B} + 2\ \tau_{event} \left(\frac{1 + 3\ B + 3\ B^2}{(1 + B)^2} \right) \right] \tag{3.3}$$

where:

Parameter		Definition (units)	Default Value
DA_{event}	=	Absorbed dose per event (mg/cm^2-event)	–
FA	=	Fraction absorbed water (dimensionless)	Chemical-specific, See Appendix B
K_p	=	Dermal permeability coefficient of compound in water (cm/hr)	Chemical-specific, See Appendix B
C_w	=	Chemical concentration in water (mg/cm^3)	Site-specific, non-ionized fraction, See Appendix A for more discussion
τ_{event}	=	Lag time per event (hr/event)	Chemical-specific, See Appendix B
t_{event}	=	Event duration (hr/event)	See Exhibit 3-2
t^*	=	Time to reach steady-state (hr) = 2.4 τ_{event}	Chemical-specific, See Eq. A.5 to A.8
B	=	Dimensionless ratio of the permeability coefficient of a compound through the stratum corneum relative to its permeability coefficient across the viable epidermis (ve) (dimensionless)	Chemical-specific, See Eq. A.1

MW (Potts and Guy, 1992) obtained from an experimental data base (the Flynn data base composed of about 90 chemicals, see DEA, Chapter 4, and Appendix B of this document) of absorption of chemicals from water through human skin in vitro.

For ionized organic compounds, Equation 3.8 can be used to estimate K_p with the appropriate K_{ow} value. Note that for ionizable organic chemicals, the K_{ow} value used in Equation 3.8 should be the K_{ow} of only species that are non-ionized. Similarly, for these chemicals, the concentration C_w used in Equations 3.2 and 3.3 should be that of the non-ionized fraction. (See Appendices A and B for more discussion on this topic.) Organic chemicals which are always ionized (including ionized but uncharged zwitterions) and ionized species of ionizable organic chemicals at the conditions of interest should be treated the same as inorganic chemicals.

For halogenated chemicals, Equation 3.8 could underestimate K_p. The Flynn data set from which Equation 3.8 was derived consists almost entirely of hydrocarbons with a relatively constant ratio of molar volume to MW. Because halogenated chemicals have a lower ratio of molar volume relative to their MW than hydrocarbons (due to the relatively weighty halogen atom), the K_p correlation based on MW of hydrocarbons will tend to underestimate permeability coefficients for halogenated organic chemicals. To address this problem, a new K_p correlation based on molar volume and log K_{ow} will be explored.

Based on the Flynn data set, Equation 3.8 can be used to predict the permeability coefficient of

EXHIBIT 3-1

PERMEABILITY COEFFICIENTS FOR INORGANICS

Compound	Permeability Coefficient K_p (cm/hr)
Cadmium	1×10^{-3}
Chromium (+6)	2×10^{-3}
Chromium (+3)	1×10^{-3}
Cobalt	4×10^{-4}
Lead	1×10^{-4}
Mercury (+2)	1×10^{-3}
Methyl mercury	1×10^{-3}
Mercury vapor	0.24
Nickel	2×10^{-4}
Potassium	2×10^{-3}
Silver	6×10^{-4}
Zinc	6×10^{-4}
All other inorganics	1×10^{-3}

chemicals with K_{ow} and MW within the following "Effective Prediction Domain" (EPD), determined via a statistical analysis (see Appendix A, Section A.1) as presented in Equations 3.9 and 3.10. Contaminants outside the EPD are identified with an asterisk (*) in Appendix B2 and B3. Note that as additional data are received, the contaminants within the EPD may change. Therefore, users of this guidance should review EPA's website at (http://www.epa.gov/oswer/riskassessment/ or http://www.epa.gov/superfund/programs/risk/ragse/index.htm) to determine what contaminants are currently inside (or outside) the EPD.

Strictly, chemicals with very large and very small K_{ow} values are outside of the EPD. Although large variances in some data points contributed to the definition of the EPD, it is defined primarily by the properties of the data used to develop Equation 3.8. With no other data presently available for chemicals with very large and very small K_{ow}, it is appropriate to use Equation 3.8 as a preliminary estimate of K_p.

For many chemicals with log K_{ow} and MW outside of the prediction domain, a fraction absorbed (FA) is estimated to account for the loss of chemicals due to

Dermal Absorbed Dose Per Event for Inorganic Compounds – Water Contact

DA_{event} (mg/cm^2-event) is calculated for inorganics or highly ionized organic chemicals as follows:

$$DA_{event} = K_p \times C_w \times t_{event} \tag{3.4}$$

where:

Parameter		Definition (units)	Default Value
DA_{event}	=	Absorbed dose per event (mg/cm^2-event)	–
K_p	=	Dermal permeability coefficient of compound in water (cm/hr)	Chemical-specific, see Exhibit A-6 and Appendix B
C_w	=	Chemical concentration in water (mg/cm^3)	Site-specific, non-ionized fraction, see Appendix A for more discussion
t_{event}	=	Event duration (hr/event)	See Exhibit 3-2

Theoretical Derivation of Permeability Coefficient for Organic Chemicals

$$K_p = \frac{K_{sc/w} \times D_{sc}}{l_{sc}} \tag{3.5}$$

or:

$$\log K_p = \log K_{sc/w} + \log \frac{D_{sc}}{l_{sc}} \tag{3.6}$$

Empirically it has been shown that (Kasting, et al., 1987):

$$\log K_{sc/w} = a \log K_{ow} + b$$

and $D_{sc}=D_o \exp(-\beta\ MV)$

where:
D_o and β are constants, characteristic of the medium through which diffusion is occurring. For hydrocarbons, MV will be related directly to molecular weight (MW). Combining these two relationships with Equation 3.6 leads to the general form:

$$\log K_p = b + a \log K_{ow} - c\ MW \tag{3.7}$$

where:

Parameter		Definition (units)	Default Value
K_p	=	Dermal permeability coefficient of compound in water (cm/hr)	Chemical-specific, see Appendix B
K_{ow}	=	Octanol/water partition coefficient (dimensionless)	Chemical-specific, see Appendix B
$K_{sc/w}$	=	equilibrium partition coefficient between the stratum corneum and water (dimensionless)	Chemical-specific
D_o	=	Diffusivity of a hypothetical molecule with a molecular volume (MV) = 0 (cm^2/hr)	Chemical-specific
β	=	Constant specific for the medium through which diffusion is occurring	Medium specific
D_{sc}	=	Effective diffusion coefficient for chemical transfer through the stratum corneum (cm^2/hr)	Chemical-specific, see Spreadsheet ORG04_01.XLS (on website given in Section 3.1.1)
l_{sc}	=	Apparent thickness of stratum corneum (cm)	10^{-3} cm
a,b,c	=	correlation coefficients which have been fitted to the Flynn's data to give Equation 3.8.	–
MV	=	Molar volume (cm^3/mol)	Chemical-specific
MW	=	Molecular weight (g/mole)	Chemical-specific

the desquamation of the skin, which would decrease the net amount of chemicals available for absorption after the exposure event (t_{event}) has ended. Predictions of chemical-specific K_p and their use in the estimation of DA_{event}, are included in Exhibit B-3 for about two hundred chemicals.

Empirical Predictive Correlation for Permeability Coefficient of Organics

$$\log K_p = -2.80 + 0.66 \log K_{ow} - 0.0056\, MW \qquad (r^2 = 0.66) \tag{3.8}$$

where:

Parameter		Definition (units)	Default Value
K_p	=	Dermal permeability coefficient of compounds in water (cm/hr)	Chemical-specific, see Appendix B
K_{ow}	=	Octanol/water partition coefficient of the non-ionized species (dimensionless)	Chemical-specific, see Appendix B
MW	=	Molecular weight (g/mole)	Chemical-specific, see Appendix B

Inorganics. Exhibit 3-1 summarizes permeability coefficients for inorganic compounds, obtained from specific chemical experimental data, as modified and updated from DEA, Table 5-3 and from Hostynek, et al. (1998). Permeability coefficients from these references are condensed for each metal and for individual valence states of specific metals. To be most protective of human health, the value listed in this exhibit represents the highest reported permeability coefficient. More detailed information is presented in Appendix A (Exhibit A-6).

3.1.2.2 Chemical Concentration in Water

One of the issues regarding the bioavailability of chemicals in water is the state of ionization, with the non-ionized form being much more readily absorbed than the ionized form. The fraction of the chemical in the non-ionized state is dependent on the pH of the water and the specific ionization constant for that chemical (pK_a). Further information on the formulas for calculating these fractions is provided in the DEA and in Appendix A. However, given the complexities of calculating the non-ionized fraction across multiple samples and multiple chemicals, it is recommended that a standard risk assessment should make the health-protective assumption that the chemical is entirely in the non-ionized state. Therefore, the total concentration of a chemical in water samples (C_w) should be equal to the total concentration of the chemical in water.

Estimates of C_w, and therefore potential impacts of dermal exposure, may be strongly influenced by the presence of particulates in the sample. Although filtra-

Boundaries of Effective Prediction Domain

$$-0.06831 \le 5.103 \times 10^{-4}\, MW + 0.05616 \log K_{ow} \le 0.5577 \tag{3.9}$$

$$-0.3010 \le -5.103 \times 10^{-4}\, MW + 0.05616 \log K_{ow} \le 0.1758 \tag{3.10}$$

where:

Parameter		Definition (units)	Default Value
K_{ow}	=	Octanol/water partition coefficient of the non-ionized species (dimensionless)	Chemical-specific, see Appendix B
MW	=	Molecular weight (g/mole)	Chemical-specific, see Appendix B

EXHIBIT 3-2

RECOMMENDED DERMAL EXPOSURE VALUES FOR CENTRAL TENDENCY AND RME RESIDENTIAL SCENARIOS – WATER CONTACT

Exposure Parameters	Central Tendency Scenario				RME Scenario			
	Showering/ Bathing		Swimming		Showering/ Bathing		Swimming	
Concentration- C_w (mg/cm^3)	Site-specific		Site-specific		Site-specific		Site-specific	
Event frequency- EV (events/day)	1		Site-specific		1		Site-specific	
Exposure frequency- EF (days/yr)	350		Site-specific		350		Site-specific	
Event duration- t_{event} (hr/event)	**Adult[1]**	**Child[2]**	**Adult**	**Child**	**Adult[1]**	**Child[2]**	**Adult**	**Child**
	0.25	0.33	Site-specific		0.58	1.0	Site-specific	
Exposure duration- ED (yr)	9	6	9	6	30	6	30	6
Skin surface area- SA (cm^2)	18,000	6,600	18,000	6,600	18,000	6,600	18,000	6,600
Dermal permeability coefficient-K_p (cm/hr)	Chemical-specific values Exhibits B-3 and B-4							

[1] Adult showering scenario used as the basis for the chemical screening for the dermal pathway, as shown in Appendix B, Exhibits B-3 and B-4. Event duration for adult exposure is based on showering data from the EFH (U.S. EPA, 1997a).
[2] Event duration for child exposure is based on bathing data from the EFH (U.S. EPA, 1997a).

tion of water samples in the field has been used to reduce turbidity and estimate the soluble fraction of chemicals in water, existing RAGS guidance (U.S. EPA, 1989) recommends that unfiltered samples be used as the basis for estimating the chemical concentration for calculating the *oral* dose. The rationale is that particulate-bound chemicals may still be available for absorption across the gastrointestinal tract. To be consistent with existing EPA guidance, it is recommended that unfiltered samples also be used as the basis for estimating a chemical concentration for calculating the *dermal* dose.

However, it should be noted that particulate-bound chemicals in an aqueous medium (e.g., suspended sediment particles) would be considered to be much less bioavailable for dermal absorption, due to inefficient adsorption of suspended particles onto the skin surface and a slower rate of absorption into the skin. The uncertainty in the estimation of the dermal dose from a water sample with high turbidity is directly proportional to the magnitude of the difference in the concentration between an unfiltered and filtered sample. The actual bioavailable concentration is likely to lie somewhere between the unfiltered and filtered sample concentrations. The impact of this health-protective assumption and relevant field factors (e.g., turbidity) should be discussed in the uncertainty section. To reduce the uncertainty in estimating the bioavailable chemical concentration, water sample collection methods that minimize turbidity should be employed (U.S. EPA, 1995b, 1996), rather than sample filtration.

3.1.2.3 Skin Surface Area

The surface area (SA) parameter describes the amount of skin exposed to the contaminated media.

Dermal Absorbed Dose – Soil Contact

$$DAD = \frac{DA_{event} \times EF \times ED \times EV \times SA}{BW \times AT} \quad (3.11)$$

where:

Parameter		Definition (units)	Default Value
DAD	=	Dermal Absorbed Dose (mg/kg-day)	–
DA_{event}	=	Absorbed dose per event (mg/cm^2-event)	Chemical-specific, see Equation 3.12
SA	=	Skin surface area available for contact (cm^2)	See Appendix C and Equations 3.13 to 3.16
EV	=	Event frequency (events/day)	See Exhibit 3-5
EF	=	Exposure frequency (days/year)	See Exhibit 3-5
ED	=	Exposure duration (years)	See Exhibit 3-5
BW	=	Body weight (kg)	70 kg (adult), 15 kg (child)
AT	=	Averaging time (days)	noncarcinogenic effects AT = ED x 365 d/yr carcinogenic effects AT = 70 yr x 365 d/yr

The amount of skin exposed depends upon the exposure scenario. For dermal contact with water, the total body surface area for adults and children is assumed to be exposed for both swimming and bathing. Since body weight and SA are dependent variables, all SA estimates used 50th percentile values in order to correlate with the average body weights. The recommended SA exposed to contaminated water for the adult resident is 18,000 cm^2. This SA value was calculated by incorporating data from Tables 6.2 and 6.3 for the Exposure Factors Handbook (U.S. EPA, 1997a), averaging the 50th percentile values for males and females.

The recommended SA value for exposure to contaminated water for the child resident is 6,600 cm^2. This SA was calculated by incorporating the data from the EFH for the 50th percentile of the total body surface area for male and female children, and calculating a time weighted average surface area for a 0-6 year old child. The lack of data for all ages led to a conservative assumption that a 0-1 year old and 1-2 year old had the same surface area as a 2-3 year old. This recommended child SA was calculated by averaging the male and female surface areas.

Dermal Absorbed Dose Per Event – Soil Contact

DA_{event} (mg/cm^2-event) is calculated as follows:

$$DA_{event} = C_{soil} \times CF \times AF \times ABS_d \quad (3.12)$$

where:

Parameter		Definition (units)	Default Value
DA_{event}	=	Absorbed dose per event (mg/cm^2-event)	–
C_{soil}	=	Chemical concentration in soil (mg/kg)	Site-specific
CF	=	Conversion factor (10^{-6} kg/mg)	10^{-6} kg/mg
AF	=	Adherence factor of soil to skin (mg/cm^2-event) (Referred to as contact rate in RAGS, Part A)	See Section 3.2.2.3 and Appendix C
ABS_d	=	Dermal absorption fraction	See Exhibit 3-4

Surface Area Exposed for Adult Resident – Soil Contact

where:

$$Exposed\ SA\ (Adult\ Resident) = SA_{head} + SA_{forearms} + SA_{hands} + SA_{lower\ legs} \quad (3.13)$$

Parameter		Definition (units)	Default Value
SA	=	Skin surface area available for contact (cm^2)	See Appendix C

Surface Area Exposed for Adult Commercial/Industrial – Soil Contact

$$Exposed\ SA\ (Adult\ Commercial/Industrial) = SA_{head} + SA_{forearms} + SA_{hands} \quad (3.14)$$

where:

Parameter		Definition (units)	Default Value
SA	=	Skin surface area available for contact (cm^2)	See Appendix C

3.1.2.4 Event Time, Frequency, and Duration of Exposure

Exhibit 3-2 summarizes the default exposure values for both surface area and exposure duration, presented as central tendency and RME. All the central tendency values were obtained from the EFH, while the RME values were derived as previously presented. Recommended event duration values are provided for a showering activity. Even though children may be bathing for a longer duration, the showering adult remains the most highly exposed receptor.

3.2 ESTIMATION OF DERMAL EXPOSURE TO CHEMICALS IN SOIL

3.2.1 STANDARD EQUATION FOR DERMAL CONTACT WITH CHEMICALS IN SOIL

The general guidance for evaluating dermal absorption of compounds from soil is presented in *Risk Assessment Guidance for Superfund* (RAGS, U.S. EPA, 1989) and is expanded upon in the DEA. This section briefly discusses the rationale and updates specific parameters. The standard equation for dermal contact with chemicals (Equation 3.11) is the same as that in Section 3.1.1. (Equation 3.1). Equation 3.12 provides DA_{event} for soil contact.

3.2.2 EXPOSURE PARAMETERS

3.2.2.1 Skin Surface Area

The skin surface area parameter (SA) describes the amount of skin exposed to the contaminated media. The amount of skin exposed depends upon the exposure scenario. Clothing is expected to limit the extent of the exposed surface area in cases of soil contact. All SA estimates used 50th percentile values to correlate with average body weights used for all scenarios and pathways. This was done to prevent inconsistent parameter combinations since body weight and SA are dependent variables. Body part-specific SAs were calculated for adult (>18 years old) and child (<1 to <6 years old) residents as described below and documented in Appendix C.

Adult resident. The adult resident was assumed to wear a short-sleeved shirt, shorts and shoes; therefore, the exposed skin surface is limited to the head, hands, forearms and lower legs. The recommended SA exposed to contaminated soil for the adult resident is 5700 cm^2 and is the average of the 50th percentile for males and females greater than 18 years of age. Surface area data were taken from EFH, Tables 6-2 (adult male) and 6-3 (adult female). Exposed SA for the adult

Surface Area Exposed for Child Resident – Soil Contact

$$Fraction\ of\ Total\ SA_{body\ part\ i} = \frac{SA\ fraction_{age\ <1} + SA\ fraction_{age\ 1<2} + \ldots + SA\ fraction_{age\ 5<6}}{6} \quad (3.15)$$

$$Exposed\ SA = (FTSA_{head})(SA_{total}) + (FTSA_{forearms})(SA_{total}) + (FTSA_{hands})(SA_{total}) + (FTSA_{lowerlegs})(SA_{total}) + (FTSA_{feet})(SA_{total}) \quad (3.16)$$

where:

Parameter		Definition (units)	Default Value
FTSA	=	Fraction of total surface area for the specified body part (cm^2)	See Appendix C
SA	=	Skin surface area available for contact (cm^2)	See Appendix C
SA_{total}	=	Total skin surface available for contact	See Appendix C
$(FTSA_i)(SA_{total})$	=	Surface area for body part "i" (cm^2)	–

resident was calculated using Equation 3.13, documented in Appendix C with the assumption that the female adult forearm SA was 45% of the arm SA (based on the adult male forearm-to-arm SA ratio).

Adult commercial/industrial. The adult commercial/industrial receptor was assumed to wear a short-sleeved shirt, long pants, and shoes; therefore, the exposed skin surface is limited to the head, hands, and forearms. The recommended SA exposed to contaminated soil for the adult commercial/industrial receptor is 3300 cm^2 and is the average of the 50th percentile for males and females greater than 18 years of age. Surface area data were taken from EFH, Tables 6-2 (adult male) and 6-3 (adult female). Exposed SA for the adult commercial/industrial receptor was calculated using Equation 3.14 and is documented in Appendix C with the assumption that the female adult forearm SA was 45% of the arm SA (based on the adult male forearm-to-arm SA ratio).

Child. The child resident (<1 to <6 years old) was assumed to wear a short-sleeved shirt and shorts (no shoes); therefore, the exposed skin is limited to the head, hands, forearms, lower legs, and feet. The recommended SA exposed to contaminated soil for the child resident is 2800 cm^2 and is the average of the 50th percentile for males and females (<1 to <6 years old). Body part-specific data for male and female children were taken from EFH, Table 6-8, as a fraction of total body surface area. Total body SAs for male and female children were taken from EFH, Tables 6-6 (male) and 6-7 (female), and used to calculate average male/female total SA (see Appendix C). Exposed SA for the child resident was calculated, using Equations 3.15 and 3.16 and is documented in Appendix C with the following assumptions: (1) because of the lack of data for certain ages, the fraction of total SA was assumed to be equal to the next oldest age group that had data and (2) the forearm-to-arm ratio (0.45) and lower leg-to-leg ratio (0.4) are equivalent to those of an adult. These assumptions introduce some uncertainty into the calculation, but are used in the absence of age-specific data.

While clothing scenarios described above for the adult and child residents may not be appropriate for all regions, the climate in some areas would allow a short-sleeved shirt and/or shorts to be worn throughout a majority of the year. In addition, in some regions of the country, children may remain barefoot throughout a major portion of the year. These clothing scenarios were chosen to ensure adequate protection for those receptors that may be exposed in the warmer climates, with the realization that risks would likely be over-estimated for some seasons.

When selecting the surface area, site-specific conditions should be evaluated in coordination with the project's risk assessors. For colder climates, the surface area may be weighted for different seasons. Because some studies have suggested that exposure can occur under clothing (Maddy, et al., 1983), these

clothing scenarios are not considered to be overly conservative.

3.2.2.2 Soil-to-Skin Adherence Factors

The adherence factor (AF) describes the amount of soil that adheres to the skin per unit of surface area. Recent data (Kissel et al., 1996; Kissel et al., 1998; and Holmes et al., 1999) provide evidence to demonstrate that 1) soil properties influence adherence, 2) soil adherence varies considerably across different parts of the body; and 3) soil adherence varies with activity.

Given these results, the Workgroup recommends that an activity which best represents all soils, body parts, and activities be selected (U.S. EPA, 1997a). Body part-weighted AFs can then be calculated and used in estimating exposure via dermal contact with soil based on assumed exposed body parts. Given that soil adherence depends upon the body part, an overall body part-weighted AF must be calculated for each activity. The assumed clothing scenario determines which body part-specific AFs are used in calculating the 50th and 95th percentile weighted AFs. The weighted AFs are used with the relative absorption, exposure frequency and duration, exposed surface area, body weight, and averaging time to estimate the dermal absorbed dose. The general equation used to calculate the weighted AF for a particular activity is shown in Equation 3.17.

Adult resident. The adult resident (>18 years old) was assumed to wear a short-sleeved shirt, shorts and shoes; therefore, the exposed skin surface was limited to the face, hands, forearms and lower legs. The weighted AFs for adult residential activities (e.g., grounds keepers, landscapers, and gardeners) were calculated using Equation 3.18 and are documented in Appendix C. Note: This calculation differs from that presented in Section 3.2.2.1 in the areas used for head and face. In the total surface area calculation presented earlier, the total head area was used. For the soil-to-skin adherence factor, empirical measurements were from the face only and the face surface area was estimated to be ⅓ the total head surface area.

Adult commercial/industrial. The adult commercial/industrial receptor was assumed to wear a short-sleeved shirt, long pants, and shoes. Therefore, the exposed skin surface was limited to the face, hands, and forearms. The weighted AFs for adult commercial/industrial activities (e.g., grounds keepers, landscapers, irrigation installers, gardeners, construction workers, equipment operators, and utility workers) were calculated using Equation 3.19, and documented in Appendix C.

Child resident. The child resident (<1 to <6 years old) was assumed to wear a short-sleeved shirt and shorts (no shoes). Therefore, the exposed skin was limited to face, hands, forearms, lower legs, and feet. Weighted AFs for children in day care and "staged" children playing in dry and wet soil activities were calculated using Equation 3.20, and documented in Appendix C.

As noted in Appendix C, body part-specific AFs for both child and adult receptors were not always available for all body parts assumed to be exposed.

Surface Area Weighted Soil Adherence Factor

$$Weighted\ AF = \frac{(AF_1)(SA_1) + (AF_2)(SA_2) + \ldots + (AF_i)(SA_i)}{SA_1 + SA_2 + \ldots + SA_i} \quad (3.17)$$

where:

Parameter		Definition (units)	Default Value
AF	=	Adherence factor of soil to skin (mg/cm^2-event) (Referred to as contact rate in RAGS, Part A)	–
AF_i	=	Overall adherence factor of soil to skin (mg/cm^2-event)	See Appendix C
SA_i	=	Skin surface area available for contact for body part "i" (cm^2)	See Appendix C

Surface Area Weighted Soil Adherence Factor for Adult Resident

$$Weighted\ AF_{adult\ resident} = \frac{(AF_{face})(SA_{face}) + (AF_{forearms})(SA_{forearms}) + (AF_{hands})(SA_{hands}) + (AF_{lowerlegs})(SA_{lowerlegs})}{SA_{face} + SA_{forearms} + SA_{hands} + SA_{lowerlegs}} \quad (3.18)$$

where:

Parameter		Definition (units)	Default Value
AF	=	Adherence factor of soil to skin (mg/cm^2-event) (Referred to as contact rate in RAGS, Part A)	–
AF_i	=	Overall adherence factor of soil to skin (mg/cm^2-event)	See Appendix C
SA_i	=	Skin surface area available for contact for body part "i" (cm^2)	See Appendix C

Surface Area Weighted Soil Adherence – Adult/Commercial

$$Weighted\ AF_{adult\ commercial} = \frac{(AF_{face})(SA_{face}) + (AF_{forearms})(SA_{forearms}) + (AF_{hands})(SA_{hands})}{SA_{face} + SA_{forearms} + SA_{hands}} \quad (3.19)$$

where:

Parameter		Definition (units)	Default Value
AF	=	Adherence factor of soil to skin (mg/cm^2-event) (Referred to as contact rate in RAGS, Part A)	–
AF_i	=	Overall adherence factor of soil to skin (mg/cm^2-event)	See Appendix C
SA_i	=	Skin surface area available for contact for body part "i" (cm^2)	See Appendix C

Weighted adherence factors for receptors were

Surface Area Weighted Soil Adherence Factor – Child

$$Weighted\ AF_{child} = \frac{(AF_{face})(SA_{face}) + (AF_{forearms})(SA_{forearms}) + (AF_{hands})(SA_{hands}) + (AF_{lowerlegs})(SA_{lowerlegs}) + (AF_{feet})(SA_{feet})}{SA_{face} + SA_{forearms} + SA_{hands} + SA_{lowerlegs} + SA_{feet}} \quad (3.20)$$

where:

Parameter		Definition (units)	Default Value
AF	=	Adherence factor of soil to skin (mg/cm^2-event) (Referred to as contact rate in RAGS, Part A)	–
AF_i	=	Overall adherence factor of soil to skin (mg/cm^2-event)	See Appendix C
SA_i	=	Skin surface area available for contact for body part "i" (cm^2)	See Appendix C

calculated using only those body parts for which AFs were available because of the difficulty in trying to assign an AF for one body part to another body part. For example, the weighted AF for the children in day care was based on the forearms, hands, lower legs, and feet (AFs for the face were not available). However, the surface area for all exposed body parts was used in calculating the dermal absorbed dose. For the day care

child example, the surface area used in estimating the DAD included the whole head, forearms, hands, lower legs and feet. Therefore, the body part that may not have had AF data available was assumed, by default, to have the same amount of soil adhered as the weighted AF.

3.2.2.3 Recommended Soil Adherence Factors

This section recommends default soil AFs for the child resident, the adult resident, and the adult commercial/industrial worker, and provides the basis for the recommendations. EPA suggests selecting an activity from AF data which best represents the exposure scenario of concern and using the corresponding weighted AF in the dermal exposure calculations (U.S. EPA, 1997a). To make this selection, activities with available AFs were categorized as those in which a typical residential child, residential adult, and commercial/industrial adult worker would be likely to engage (see Appendix C). Within each receptor category, activities were ranked in order from the activity with the lowest to highest weighted AF (50th percentile) (Exhibit 3-3). The 50th percentile weighted AF was used in ranking the activities from those with the lowest to highest weighted AFs, because the 50th percentile is a more stable estimation of the true AF (i.e., it is not affected as significantly by outliers as the 95th percentile).

As with other contact rates (e.g., soil ingestion), the recommended default value is a conservative, health protective value. To maintain consistency with this approach (i.e., recommending a high-end of a mean), two options exist when recommending default weighted AFs: (1) select a central tendency (i.e., typical) soil contact activity and use the high-end weighted AF (i.e., 95th percentile) for that activity; or (2) select a high-end (i.e., reasonable but higher exposure) soil contact activity and use the central tendency weighted AF (i.e., 50th percentile) for that activity.

It is not recommended that a high-end soil contact activity be used with a high-end weighted AF for that activity, as this use would not be consistent with the use of a reasonable maximum exposure (RME) scenario. The use of these values also needs to be evaluated when combining multiple exposure pathways to insure that an overall RME is being maintained.

Adult resident. Given that there were data available for a wide variety of activities that an adult resident may engage in, a high-end soil contact activity was selected and the central tendency weighted AF (50th percentile) was derived for that activity. In so doing, the recommended weighted AF for an adult resident is 0.07 mg/cm^2, and is based on the 50th percentile weighted AF for gardeners (the activity determined to represent a reasonable, high-end activity). The basis for this recommendation is as follows: (1) although no single activity would represent the activities an adult resident engages in, a comparison of the gardener 50th percentile weighted AF with the other residential-type activities (Appendix C) shows that gardening represents a high-end soil contact activity; (2) common sense suggests that gardening represents a high-end soil contact activity, whereas, determining which of the other activities (i.e., grounds keeping and landscaping/rockery) would represent a reasonable, central tendency (i.e., typical) soil contact activity would be difficult; and (3) selecting the central tendency weighted AF (i.e., 50th percentile) of a high-end soil contact activity is consistent with an RME for contact rates.

Child resident (<1 to <6 years old). Available data on soil AFs for children were limited to children (1-6½ years old) playing indoors and outdoors (3.5-4 hours) at a day care center (reviewed in U.S. EPA, 1997a) and children (8-12 years old) playing for 20 minutes with an assortment of toys and implements in a preconstructed 8'x8' soil bed (i.e., "staged" activity) containing dry or wet soil (see Kissel et al., 1998, and Appendix C). Therefore, it was not possible to identify a reasonable worst-case soil contact activity as was done for the adult resident. As such, both of the following approaches were used in determining the appropriate weighted AF for children: (1) selecting a central tendency (i.e., typical) soil contact activity using the high-end weighted AF (i.e., 95th percentile) for that activity; and, (2) selecting a high-end soil contact activity using the central tendency weighted AF (i.e., 50th percentile) for that activity. The recommended weighted AF for a child resident (<1 to <6 years old) is 0.2 mg/cm^2 and is based on the 95th percentile weighted AF for children playing at a day care center (central tendency soil contact activity) or the 50th percentile for children playing in wet soil (high-end soil contact activity).

EXHIBIT 3-3

ACTIVITY SPECIFIC-SURFACE AREA WEIGHTED SOIL ADHERENCE FACTORS

Exposure Scenario	Age (years)	Weighted Soil Adherence Factor (mg/cm^2)	
		Geometric Mean	95th Percentile
CHILDREN[1]			
Indoor Children	1-13	0.01	0.06
Daycare Children (playing indoors and outdoors)	1-6.5	0.04	0.3
Children Playing (dry soil)	8-12	0.04	0.4
Children Playing (wet soil)	8-12	0.2	3.3
Children-in-Mud[5]	9-14	21	231
RESIDENTIAL ADULTS[2]			
Grounds Keepers	>18	0.01	0.06
Landscaper/Rockery	>18	0.04	0.2
Gardeners	>16	0.07	0.3
COMMERCIAL/INDUSTRIAL ADULTS[3]			
Grounds Keepers	>18	0.02	0.1
Landscaper/Rockery	>18	0.04	0.2
Staged Activity: Pipe Layers (dry soil)	>15	0.07	0.2
Irrigation Installers	>18	0.08	0.3
Gardeners	>16	0.1	0.5
Construction Workers	>18	0.1	0.3
Heavy Equipment Operators	>18	0.2	0.7
Utility Workers	>18	0.2	0.9
Staged Activity: Pipe Layers (wet soil)	>15	0.6	13
MISCELLANEOUS ACTIVITIES[4]			
Soccer Players #1 (teens, moist conditions)	13-15	0.04	0.3
Farmers	>20	0.1	0.4
Rugby Players	>21	0.1	0.6
Archeologists	>19	0.3	0.5
Reed Gatherers	>22	0.3	27
Soccer Players #2 (adults)	>18	0.01	0.08

EXHIBIT 3-3 (continued)

ACTIVITY SPECIFIC-SURFACE AREA WEIGHTED SOIL ADHERENCE FACTORS

[1] Weighted AF based on exposure to face, forearms, hands, lower legs, & feet.

[2] Weighted AF based on exposure to face, forearms, hands, & lower legs.

[3] Weighted AF based on exposure to face, forearms, & hands.
Note: this results in different weighted AFs for similar activities between residential and commercial/industrial exposure scenarios.

[4] Weighted AF based on all body parts for which data were available.

[5] Information on soil adherence values for the children-in-mud scenario is provided to illustrate the range of values for this type of activity. However, the application of these data to the dermal dose equations in this guidance may result in a significant overestimation of dermal risk. Therefore, it is recommended that the 95th percentile AF values not be used in a quantitative dermal risk assessment.
See Exhibit C-4 for bounding estimates.

Children playing at a day care center represent a central tendency (i.e., typical) activity given that: (1) the children played both indoors and outdoors; (2) the clothing worn was not controlled (i.e., some subjects wore long pants, long-sleeve shirts, and/or shoes); and (3) soil conditions were not controlled (e.g., other soil types, moisture content, etc., could result in higher AFs). The 95th percentile weighted AF for children playing at the day care center is a known, reasonable, "real-life" activity that represents the majority of the population, given that children 1 to 6 years old are either in day care or at home and are likely engaging in activities similar to those at the day care center, and represents a high-end of a typical activity.

EXHIBIT 3-4

RECOMMENDED DERMAL ABSORPTION FRACTION FROM SOIL

Compound	Dermal Absorption Fraction (ABS_d)[1]	Reference
Arsenic	0.03	Wester, et al. (1993a)
Cadmium	0.001	Wester, et al. (1992a) U.S. EPA (1992a)
Chlordane	0.04	Wester, et al. (1992b)
2,4-Dichlorophenoxyacetic acid	0.05	Wester, et al. (1996)
DDT	0.03	Wester, et al. (1990)
TCDD and other dioxins -if soil organic content is >10%	0.03 0.001	U.S. EPA (1992a)
Lindane	0.04	Duff and Kissel (1996)
Benzo(a)pyrene and other PAHs	0.13	Wester, et al. (1990)
Aroclors 1254/1242 and other PCBs	0.14	Wester, et al.(1993b)
Pentachlorophenol	0.25	Wester, et al. (1993c)
Semivolatile organic compounds	0.1	—

[1] The values presented are experimental mean values.

The "staged" activity of children playing in wet soil for 20 minutes under controlled conditions (i.e., all subjects were clothed similarly, the duration of soil contact was controlled, and the soil properties were characterized) is a high-end soil contact activity because: (1) the children were in direct contact with soil for the full duration of the activity; and (2) the children played in wet soil, which is known to have higher AFs than dry soil, for the duration of the activity. The 50th percentile weighted AF for children playing in wet soil is a central tendency estimate of a high-end soil contact activity.

Use of the 95th percentile weighted AF for children playing at a day care center (0.3 mg/cm^2) or the 50th percentile for children playing in wet soil (0.2 mg/cm^2) as a recommended weighted AF for a child resident (<1 to <6 years old) is consistent with recommending a high-end of a mean for contact rates.

While this value (0.2 mg/cm^2) is at the lower end of the range of soil adherence factors reported in DEA and based on Lepow et al. (1975) and Roels et al. (1980) studies, those studies were not designed to study soil adherence and only allowed calculation of soil adherence to hands. In addition, the central-tendency adherence factor of 0.2 mg/cm^2 estimated here is based on soil adherence studies for all of the relevant body parts (i.e., head, hands, forearms, lower-legs, and feet). Kissel et al. (1998) reports soil adherence factors for children's hands of 0.5-3 mg/cm^2 (median of 1 mg/cm^2) for relatively moist soil, which is comparable to the range of values previously reported for soil adherence to children's hands (0.5-1.5 mg/cm^2; U.S. EPA, 1997a). Exhibit C-2 contains data used to calculate the central tendency and high end AFs for children.

Commercial/industrial adult worker. Given that there were data available for a wide variety of activities that a commercial/industrial adult worker may engage in, a high-end soil contact activity was selected and the central tendency weighted AF (50th percentile) derived for that activity. In so doing, the recommended weighted AF for a commercial/industrial adult worker is 0.2 mg/cm^2 and is based on the 50th percentile weighted AF for utility workers (the activity determined to represent a high-end contact activity). The bases for this recommendation are as follows: (1) although no single activity would be representative of activities a commercial/industrial adult worker engages in, a comparison of the utility worker 50th percentile weighted AF with other commercial/industrial-type activities (Exhibit 3-3) shows that the utility worker represents a high-end soil contact activity (i.e., grounds keepers, landscaper/rockery, irrigation installers, gardeners, construction workers); (2) a combination of common sense and data on the weighted AFs supports the assumption that utility worker activities represent a high-end soil contact activity, whereas, determining which of other measured activities might represent a reasonable, central tendency (i.e., typical) soil contact activity would be difficult; and (3) selecting the central tendency weighted AF (i.e., 50th percentile) of a high-end soil contact activity is consistent with a RME forcontact rates.

Recreational. No specific default values are being recommended for a recreational scenario since many site-specific concerns will impact the choice of exposure variables, such as, climate, geography, location, and land-use. The risk assessors, in consultation with the project team, should reach consensus on the need to evaluate this scenario and the inputs before incorporating this into the risk assessment. The EFH should be consulted to obtain appropriate exposure estimates.

3.2.2.4 Dermal Absorption Fraction from Soil

DEA (Chapter 6) presents a methodology for evaluating dermal absorption of soil-borne contaminants. In that document, ORD reviewed the available experimental data for dermal absorption from contaminated soil and presented recommendations for three compounds/classes. Recommendations were presented as ranges to account for uncertainty which may arise from different soil types, loading rates, chemical concentrations, and other conditions. In RAGS Part E, selection of a single value is based on recommended ORD ranges to simplify this risk calculation. In addition, recommended values for other compounds according to review of literature and default values for classes of compounds are provided. For tetrachlorodibenzo-p-dioxin (TCDD), sufficient data allow specific recommendations based on organic content of the soil.

Values in Exhibit 3-4 have been determined to be applicable using the Superfund default human exposure assumptions, and are average absorption values. Other

values will be added to this list as results of further research become available. However, as an interim method, dermal exposure to other compounds should be treated qualitatively in the uncertainty section or quantitatively using default values after presenting the relevant studies to the regional risk assessors so that absorption factors can be agreed upon on a site-specific basis before the start of the risk assessment. Particular attention should be given to dermally active compounds, such as benzo(a)pyrene, and they should be addressed fully as to their elevated risk by this route of exposure.

This guidance provides a default dermal absorption fraction for semivolatile organic compounds (SVOCs) of 10% as a screening method for the majority of SVOCs without dermal absorption fractions. This fraction is suggested because the experimental values in Exhibit 3-4 are considered representative of the chemical class for screening evaluations. If these are used quantitatively, they represent another uncertainty that should be presented and discussed in the risk assessment. There are no default dermal absorption values presented for volatile organic compounds nor inorganic classes of compounds. The rationale for this is that in the considered soil exposure scenarios, volatile organic compounds would tend to be volatilized from the soil on skin and should be accounted for via inhalation routes in the combined exposure pathway analysis. For inorganics, the speciation of the compound is critical to the dermal absorption and there are too little data to extrapolate a reasonable default value.

Although Equation 3.12 implies that the ABS_d is independent of AF, this independence may not be the case. Experimental evidence suggests that ABS_d may be a function of AF (Duff and Kissel, 1996 and Yang, 1989). Specifically, ABS_d has been observed to increase as the AF decreases below the quantity of soil necessary to completely cover the skin in a thin layer of soil particles, which is discussed in the DEA as the mono-layer concept. This mono-layer will vary according to physical characteristics of the applied soil, e.g., particle size. Most significantly, nearly all experimental determinations of ABS_d have been conducted at loading rates larger than required to completely cover the skin, while the recommended default values for AF for both adult and children are at or less than that required to establish a mono-layer. The absolute effect of soil loading on these parameters is not sufficiently understood to warrant adjustment of the experimentally determined values. Consequently, actual ABS_d could be larger than experimentally determined and the effect of this uncertainty should be appropriately presented in the risk assessment.

Equation 3.12 includes no explicit effect of exposure time, which also adds to the uncertainty and consequently assumes exposure time is the same as in the experimental study that measured ABS_d. For values presented, the exposure time per event is 24 hours. Site-specific exposure scenarios should not adjust ABS_d per event but rather adjust the exposure frequency (EF) and exposure duration (ED) to account for site conditions.

A discussion of theoretical models that estimate DA_{event} on the basis of a soil permeability coefficient rather than ABS_d is presented in DEA. The permeability coefficient approach offers some advantages in that the partitioning coefficient from soil should remain constant over a wider range of conditions, such as the amount of soil on the skin and the concentration of the contaminant in the soil. However, as soil partitioning procedures are not well developed, the Workgroup recommends that the absorbed fraction per event procedures presented in this guidance be used to assess dermal uptake for soil.

3.2.2.5 Age-Adjusted Dermal Factor

An age-adjusted dermal exposure factor (SFS_{adj}) is used when dermal exposure is expected throughout childhood and into adult years. This accounts for changes in surface area, body weight and adherence factors over an extended period of time. The use of SFS_{adj} incorporates body weight, surface area, exposure duration and adherence factor parameters from the risk equation. To calculate SFS_{adj}, assumptions recommended above for the child (age 0-6 years) and adult (age 7-30 years) were calculated using data from the EFH and the methodology described for the residential child. The recommended age-adjusted dermal factor is calculated using Equation 3.21.

3.2.2.6 Event Time, Exposure Frequency, and Duration

This guidance assumes one event per day, during which a percentage of a chemical quantity is absorbed

Age-Adjusted Dermal Exposure Factor

$$SFS_{adj} = \frac{(SA_{1-6})(AF_{1-6})(ED_{1-6})}{(BW_{1-6})} + \frac{(SA_{7-31})(AF_{7-31})(ED_{7-31})}{(BW_{7-31})} \quad (3.21)$$

$$SFS_{adj} = \frac{(2800cm^2)(0.2mg/cm^2-event)(6yr)}{(15kg)} + \frac{(5700cm^2)(0.07mg/cm^2-event)(24yr)}{(70kg)}$$

$$SFS_{adj} = 360 \ mg-yrs/kg-event$$

where:

Parameter		Definition (units)	Default Value
SFS_{adj}	=	Age-adjusted dermal exposure factor (mg-yrs/kg-events)	–
AF_{1-6}	=	Adherence factor of soil to skin for a child (1 - 6 years) (mg/cm^2-event) (Referred to as contact rate in RAGS, Part A)	0.2 (EFH, EPA 1997a)
AF_{7-31}	=	Adherence factor of soil to skin for an adult (7 - 31 years) (mg/cm^2-event) (Referred to as contact rate in RAGS, Part A)	0.07 (EFH, EPA 1997a)
SA_{1-6}	=	Skin surface area available for contact during ages 1 - 6 (cm^2)	2,800
SA_{7-31}	=	Skin surface area available for contact during ages 7 - 31 (cm^2)	5,700
ED_{1-6}	=	Exposure duration during ages 1 - 6 (years)	6
ED_{7-31}	=	Exposure duration during ages 7 - 31 (years)	24
BW_{1-6}	=	Average Body weight during ages 1 - 6 (kg)	15
BW_{7-31}	=	Average Body weight during ages 7 - 31 (kg)	70

systemically, and exposure time is the same as in the experimental study that measured ABS_d (i.e., 24 hours), as recommended in Exhibit 3-4.

Limited data suggest that absorption of a chemical from soil depends on time. However, information is insufficient to determine whether that absorption is linear, sublinear or supralinear with time. Whether these assumptions would result in an over- or under-estimate of exposure and risk is unclear. Site-specific exposure scenarios should not scale the dermal absorption factor of the event time. The exposure frequency for the RME is referenced from RAGS Part A (U.S. EPA, 1989) but may be adjusted to reflect site-specific conditions.

The recommended central tendency and RME values for exposure duration (Exhibit 3-5) are referenced from RAGS Part A (U.S. EPA, 1989), but may be adjusted to reflect site-specific conditions.

3.3 ESTIMATION OF DERMAL EXPOSURES TO CHEMICALS IN SEDIMENT

Exposures to sediment will differ from exposures to soil due to potential differences in the chemical and physical properties between the two media and differing conditions under which these types of exposures occur. Since studies of dermal exposure to sediments are limited, it is recommended that the same risk assessment approach described in this document for soil exposures be used for sediments, with the following considerations:

EXHIBIT 3-5

RECOMMENDED DERMAL EXPOSURE VALUES FOR CENTRAL TENDENCY AND RME RESIDENTIAL AND INDUSTRIAL SCENARIOS – SOIL CONTACT

Exposure Parameters		Central Tendency		RME Scenario	
		Residential	Industrial	Residential	Industrial
Concentration- C_{soil} (mg/kg)		site-specific values			
Event frequency (events/day)		1	1	1	1
Exposure frequency (days/yr)		site-specific	219	350	250
Exposure duration (yr)		9	9	30	25
Skin surface area (cm^2)	Adult	5,700	3,300	5,700	3,300
	Child	2,800	NA	2,800	NA
Soil adherence factor (mg/cm^2)	Adult	0.01	0.02	0.07	0.2
	Child	0.04	NA	0.2	NA
Dermal absorption fraction		chemical-specific values (Exhibit 3-4)			

NA: not applicable

- Sediment samples must be located in areas in which individuals are likely to come into direct contact with the sediments. For wading and swimming, this includes areas which are near shore and in which sediments are exposed at some time during the year. Sediments which are consistently covered by considerable amounts of water are likely to wash off before the individual reaches the shore.

- Since data are generally reported in dry weight, the impact of moisture content in the in situ sample (i.e., wet weight) on exposure and uptake should be considered and discussed in the uncertainty section. The greater the moisture content of a sediment sample, the greater the difference in dry vs. wet weight contaminant concentration. The sediment adherence data reported in this guidance are on a dry weight basis. Chemical concentrations in sediment are also generally reported on a dry weight basis. This provides a consistent basis for combining these parameters to estimate the amount of chemical on skin.

- When applying standard equations for DA_{event} (Eq. 3.12) and DAD (Eq. 3.11) to sediment scenarios, assumptions about surface area exposed, frequency, and duration of exposure will depend on site-specific conditions.

- The amount of chemical absorbed from sediment is dependent on a number of chemical, physical and biological factors. The relative importance of some of these factors on absorption may differ between soils and sediments. Until more information becomes available, the same dermal absorption fraction for soils (Exhibit 3-4) should be applied to sediments. The uncertainties associated with this approach should be discussed in the uncertainty section of the risk assessment.

- The adherence factor is perhaps, the most uncertain parameter to estimate for sediment exposures. Increasing moisture content will increase the ability of sediments and soils to adhere to skin, as demonstrated by comparing soil adherence for the same activity in wet and dry soil. The increased moisture content may also affect the relative percent absorbed.

- In addition, assumptions about soil loading (or adherence) will affect absorption estimates For example, as soil loading increases, the fraction absorbed will be constant until a critical level is reached at which the skin surface is uniformly covered by soil (defined as the mono-layer) (Duff and Kissel, 1996). The soil loading at which a mono-layer exists is dependent on grain size. It is recommended that the value chosen for adherence be consistent with the activity and surface area assumptions as well as the mono-layer concept. Exhibit C-4 presents upper bound estimates calculated for the Soil Conservation Service classifications using mean particle diameters and a simplified packing model. These values can be used as bounding estimates in constructing site-specific exposure parameters. The impact of the adherence factor assumptions on absorption should be discussed in the uncertainty section.

CHAPTER 4

TOXICITY ASSESSMENT

4.1 PRINCIPLES OF ROUTE-TO-ROUTE EXTRAPOLATION

Dermal contact with contaminants can result in direct toxicity at the site of application and/or contribute to systemic toxicity via percutaneous absorption. The issue of direct toxicity is addressed in Section 4.4. Ideally, a route-specific (i.e., dermal) toxicity factor would not only consider portal-of-entry effects (i.e., direct toxicity) but would also provide dosimetry information on the dose-response relationship for systemic effects via percutaneous absorption.

In the absence of dermal toxicity factors, EPA has devised a simplified paradigm for making route-to-route (oral-to-dermal) extrapolations for systemic effects. This process is outlined in Appendix A of RAGS/HHEM (U.S. EPA, 1989). Primarily, it accounts for the fact that most oral reference doses (RfDs) and slope factors are expressed as the amount of substance administered per unit time and body weight, whereas exposure estimates for the dermal pathway are expressed as absorbed dose. The process utilizes the dose-response relationship obtained from oral administration studies and makes an adjustment for absorption efficiency to represent the toxicity factor in terms of absorbed dose.

This approach is subject to a number of factors that might compromise the applicability of an oral toxicity factor for dermal exposure assessment. The estimation of oral absorption efficiency, to adjust the toxicity factor from administered to absorbed dose, introduces uncertainty. Part of this uncertainty relates to distinctions between the terms "absorption" and "bioavailability." Typically, the term absorption refers to the "disappearance of chemical from the gastrointestinal lumen," while oral bioavailability is defined as the "rate and amount of chemical that reaches the systemic circulation unchanged." That is, bioavailability accounts for both absorption and pre-systemic metabolism. Although pre-systemic metabolism includes both gut wall and liver metabolism, for the most part it is liver metabolism or liver "first pass" effect that plays the major role.

In the absence of metabolic activation or detoxification, toxicity adjustment should be based on bioavailability rather than absorption because the dermal pathway purports to estimate the amount of parent compound entering the systemic circulation. Metabolism in the gut wall and skin can serve to complicate this otherwise simplified adjustment process. Simple adjustment of the oral toxicity factor, based on oral absorption efficiency, does not account for metabolic by-products that might occur in the gut wall but not the skin, or conversely in the skin, but not the gut wall.

More importantly the oral administered dose experiences the liver "first pass"effect. The efficiency of "first pass" metabolism and whether this is an activating or detoxifying process determines the nature of the impact this effect has on route-to-route extrapolations. One example is a compound that exhibits poor oral systemic bioavailability due to a prominent "first pass" effect which creates a highly toxic metabolite. The adjusted dermal toxicity factor may overestimate the true dose-response relationship because it would be based upon the amount of parent compound in the systemic circulation rather than on the toxic metabolite. Additionally, percutaneous absorption may not generate the toxic metabolite to the same rate and extent as the gastrointestinal route.

Toxicity is a function of contaminant concentration at critical sites-of-action. Absorption rate, as well as extent of absorption, determines contaminant concentration at a site-of-action. Differences in the anatomic barriers of the gastrointestinal tract and the skin can affect rate as well as the extent of absorption; therefore, the route of exposure may have significant dose-rate effects at the site-of-action.

4.2 ADJUSTMENT OF TOXICITY FACTORS

Methodologies for evaluating percutaneous absorption, as described in *DEA* give rise to an estimation of absorbed dose. However, Integrated Risk Information System (IRIS)-verified indices of toxicity (e.g., RfDs, slope factors) are typically based on administered dose. Therefore, to characterize risk from the dermal exposure pathway, adjustment of the oral toxicity factor to represent an absorbed rather than administered dose is necessary. This adjustment accounts for the absorption efficiency in the "critical study," which forms the basis of the RfD. For example, in the case where oral absorption in the critical study is essentially complete (i.e., 100%), the absorbed dose is equivalent to the administered dose, and therefore no toxicity adjustment is necessary. When gastrointestinal absorption of a chemical in the critical study is poor (e.g., 1%), the absorbed dose is much smaller than the administered dose; thus, toxicity factors based on absorbed dose should be adjusted to account for the difference in the absorbed dose relative to the administered dose.

In effect, the magnitude of toxicity factor adjustment is inversely proportional to the absorption fraction in the critical study. That is, when absorption efficiency in the critical study is high, the absorbed dose approaches the administered dose resulting in little difference in a toxicity factor derived from either the absorbed or administered dose. As absorption efficiency in the critical study decreases, the difference between the absorbed dose and administered dose increases. At some point, a toxicity factor based on absorbed rather than administered dose should account for this difference in dose. In practice, an adjustment in oral toxicity factor (to account for "absorbed dose" in the dermal exposure pathway) is recommended when the following conditions are met: (1) the toxicity value derived from the critical study is based on an administered dose (e.g., delivery in diet or by gavage) in its study design; (2) a scientifically defensible database demonstrates that the gastrointestinal (GI) absorption of the chemical in question, from a medium (e.g., water, feed) similar to the one employed in the critical study, is significantly less than 100% (e.g., <50%). A cutoff of 50% GI absorption is recommended to reflect the intrinsic variability in the analysis of absorption studies. Thus, this cutoff level obviates the need to make comparatively small adjustments in the toxicity value that would otherwise impart on the process a level of accuracy that is not supported by the scientific literature.

If these conditions are not met, a default value of complete (i.e., 100%) oral absorption may be assumed, thereby eliminating the need for oral toxicity-value adjustment. The Uncertainty Analysis could note that employing the oral absorption default value may result in underestimating risk, the magnitude of which being inversely proportional to the true oral absorption of the chemical in question.

The recommended GI absorption values (ABS_{GI}) for those compounds with chemical-specific dermal absorption factors from soil are presented in Exhibit 4-1. For those organic chemicals that do not appear on the table, the recommendation is to assume a 100% ABS_{GI} value, based on review of literature, indicating that organic chemicals are generally well absorbed (>50%) across the GI tract. Absorption data for inorganics are also provided in Exhibit 4-1, indicating a wide range of absorption values for inorganics. Despite the wide range of absorption values for inorganics, the recommendation is to assume a 100% ABS_{GI} value for inorganics that do not appear in this table. This assumption may contribute to an underestimation of risk for those inorganics that are actually poorly absorbed. The extent of this underestimation is inversely proportional to the actual GI absorption. These criteria are recommended for the adjustment of toxicity values for the assessment of both soil and water contact.

Equation 4.1 indicates that as the ABS_{GI} value decreases, the greater is the contribution of the dermal pathway to overall risk relative to the ingestion pathway. Therefore, the ABS_{GI} can greatly influence the comparative importance of the dermal pathway in a risk assessment.

4.3 CALCULATION OF ABSORBED TOXICITY VALUES

Once the criteria for adjustment have been met and a specific ABS_{GI} value has been identified, a toxicity factor that reflects the absorbed dose can be

Impact of Oral Absorption Efficiency on the Ratio of Dermal to Ingestion Risk

$$\frac{Dermal\ Risk}{Ingestion\ Risk} \propto \frac{1}{ABS_{GI}} \tag{4.1}$$

where:

Parameter		Definition (units)	Default Value
ABS_{GI}	=	Fraction of contaminant absorbed in gastrointestinal tract (dimensionless) in the critical toxicity study	Chemical-specific, see Exhibit 4-1 and Appendix B

calculated from the oral toxicity values as presented in Equations 4.2 and 4.3.

The RfD_{ABS} and SF_{ABS} should be used in the calculation of dermal risk, as described in Chapter 5.

4.4 DIRECT TOXICITY

The discussion in Section 4.2 on toxicity factor adjustment is based on the evaluation of chronic systemic effects resulting from GI absorption. Chapter 3 of this document provides a methodology for estimating a systemically absorbed dose secondary to dermal contact with chemicals in water and soil. However, dermal contact with a chemical may also result in direct dermal toxicity, such as allergic contact dermatitis, urticarial reactions, chemical irritation, and skin cancer. EPA recognizes that the dose-response relationship for the portal-of-entry effects in the skin are likely to be independent of any associated systemic toxicity exhibited by a particular chemical. However, at this time, chemical specific dermal toxicity factors are not available. Therefore, this dermal risk assessment guidance does not address potential dermal toxicity associated with direct contact. The dermal risk assessment methodology in this guidance may be revised to incorporate additional information on portal-of-entry effects as it becomes available.

Derivation of Cancer Slope Factor Based on Absorbed Dose

$$SF_{ABS} = \frac{SF_O}{ABS_{GI}} \tag{4.2}$$

where:

Parameter		Definition (units)	Default Value
SF_{ABS}	=	Absorbed slope factor	Chemical-specific, See Exhibit 4-1
SF_O	=	Oral slope factor $(mg/kg\text{-}day)^{-1}$	Chemical-specific
ABS_{GI}	=	Fraction of contaminant absorbed in gastrointestinal tract (dimensionless) in the critical toxicity study	Chemical-specific, see Exhibit 4-1 and Appendix B

Derivation of Reference Dose Based on Absorbed Dose

$$RfD_{ABS} = RfD_O \times ABS_{GI} \tag{4.3}$$

where:

Parameter		Definition (units)	Default Value
RfD_{ABS}	=	Absorbed reference dose (mg/kg-day)	Chemical-specific, see Exhibit 4-1
RfD_O	=	Reference dose oral (mg/kg-day)	Chemical-specific
ABS_{GI}	=	Fraction of contaminant absorbed in gastrointestinal tract (dimensionless) in the critical toxicity study	Chemical-specific, see Exhibit 4-1 and Appendix B

EXHIBIT 4-1

SUMMARY OF GASTROINTESTINAL ABSORPTION EFFICIENCIES AND RECOMMENDATIONS FOR ADJUSTMENT OF TOXICITY FACTORS FOR SPECIFIC COMPOUNDS

Compound	GI Absorption				IRIS Critical Toxicity Study			Adjust?
	Ref[1]	Species	Dosing Regimen	% Absorbed ABS_{GI}	Species	Dosing Regimen	Toxicity Factor	
Organics								
Chlordane	Ewing, 1985 Ohno, 1986	Rats	assume aqueous gavage	80%	Mice	diet	SF	No
					Mice	inhalation	RfD	
2,4-Dichlorophenoxyacetic acid (2,4-D)	Knopp, 1992 Pelletier, 1989	Rats	assume aqueous gavage	>90%	Rats	diet	RfD	No
DDT	Keller, 1980	Rats	vegetable oil	70-90%	Rats	dissolved in oil, mixed with diet	RfD	No
Pentachlorophenol	Korte, 1978	Rats	diet	76%	Rats	diet	RfD	No
	Meerman, 1983	Rats	water	100%				
Polychlorinated biphenyls (PCBs)	Albro, 1972	Rats	squalene	96%	Rats	diet	SF	No
	Muhlebach, 1981	Rats	emulsion	80%				
	Tanabe, 1981	Rats	corn oil	81%				
Polycyclic aromatic hydrocarbons(PAHs)	Chang, 1943	Rats	starch solution	58%	Mice	diet	SF	No
	Hecht, 1979	Rats	diet	89%				

EXHIBIT 4-1 (Continued)

SUMMARY OF GASTROINTESTINAL ABSORPTION EFFICIENCIES AND RECOMMENDATIONS FOR ADJUSTMENT OF TOXICITY FACTORS FOR SPECIFIC COMPOUNDS

Compound	GI Absorption				IRIS Critical Toxicity Study			Adjust?
	Ref[1]	Species	Dosing Regimen	% Absorbed ABS_{GI}	Species	Dosing Regimen	Toxicity Factor	
TCDD	Fries, 1975	Rats	diet	50-60%	under review			No
	Piper, 1973	Rats	diet	70%				
	Rose, 1976	Rats	corn oil	70-83%				
Other Dioxins/ Dibenzofurans	ATSDR, 1994a	multiple studies		>50%	under review			No
All other organic compounds	multiple references			generally >50%	multiple studies		RfD or SF	No
Inorganics								
Antimony	Waitz, 1965	Rats	water	15%	Rat	water	RfD	Yes
Arsenic (arsenite)	Bettley, 1975	Human	assume aqueous	95%	Human	water	SF	No
Barium	Cuddihy and Griffith, 1972 Taylor, 1962	Dog	water	7%	Human	water	RfD	Yes
Beryllium	Reeves, 1965	Rats	water	0.7%	Rat	water	RfD	Yes
Cadmium	IRIS, 1999	Human	diet	2.5%	Human	diet and water	RfD	Yes
		Human	water	5%				Yes
Chromium (III)	Donaldson and Barreras, 1996 Keim, 1987	Rats	diet/water	1.3%	Rat	diet	RfD	Yes

EXHIBIT 4-1 (Continued)

SUMMARY OF GASTROINTESTINAL ABSORPTION EFFICIENCIES AND RECOMMENDATIONS FOR ADJUSTMENT OF TOXICITY FACTORS FOR SPECIFIC COMPOUNDS

Compound	GI Absorption				IRIS Critical Toxicity Study			Adjust?
	Ref[1]	Species	Dosing Regimen	% Absorbed ABS_{GI}	Species	Dosing Regimen	Toxicity Factor	
Chromium (VI)	Donaldson and Barreras, 1996 MacKenzie, 1959 Sayato, 1980	Rats	water	2.5%	Rat	water	RfD	Yes
Cyanate	Farooqui and Ahmed, 1982	Rats	assume aqueous	>47%	Rat	diet	RfD	No
Manganese	Davidsson, 1989 IRIS, 1999 Ruoff, 1995	Human	diet/water	4%	Human	diet/water	RfD	Yes
Mercuric chloride (other soluble salts)	IRIS, 1999	Rats	water	7%	Rat	oral gavage in water; 2X/week	RfD	Yes
Insoluble or metallic mercury	ATSDR, 1994b	Human	acute inhalation of Hg vapor	74-80%	Human	Inhalation	RfC	No
Methyl mercury	Aberg, 1969	Human	aqueous	95%	Human	diet	RfD	No
Nickel	Elakhovskaya, 1972	Human	diet/water	4%	Rat	diet	RfD	Yes
Selenium	Young, 1982	Human	diet	30-80%	Human	diet	RfD	No
Silver	Furchner, 1968 IRIS, 1999	Dogs	aqueous	4%	Human	i.v. dose	RfD (based on estimated oral dose)	Yes

EXHIBIT 4-1 (Continued)

SUMMARY OF GASTROINTESTINAL ABSORPTION EFFICIENCIES AND RECOMMENDATIONS FOR ADJUSTMENT OF TOXICITY FACTORS FOR SPECIFIC COMPOUNDS

Compound	GI Absorption				IRIS Critical Toxicity Study			Adjust?
	Ref[1]	Species	Dosing Regimen	% Absorbed ABS_{GI}	Species	Dosing Regimen	Toxicity Factor	
Thallium	Lie, 1960	Rats	aqueous	100%	Rat	water gavage	RfD	No
Vanadium	Conklin, 1982	Rats	gavage	2.6%	Rat	diet as V_2O_5	RfD	Yes
Zinc	ATSDR, 1994c	Human	diet	highly variable	Human	diet supplement	RfD	No

[1] Literature references are listed here by first author. Complete citations are provided in Reference Section.

CHAPTER 5

RISK CHARACTERIZATION

5.1 QUANTITATIVE RISK EVALUATION

5.1.1 RISK CALCULATIONS

In contrast to the calculation of average lifetime dose for the oral and inhalation routes of exposure, which typically are based on an administered dose, the evaluation of exposure for the dermal route typically is based on an estimated absorbed dose, or dermal absorbed dose (DAD). The DAD term generally is calculated separately for the water and soil pathways, as described in Chapter 3. In Chapter 4, the oral toxicity values generally are adjusted according to the estimated extent of gastrointestinal absorption in critical toxicity studies. Once the DAD and the adjusted toxicity values have been derived, the cancer risk and hazard index for the dermal route should be calculated using Equations 5.1 and 5.2. For evaluating the risk, the age-adjusted child/adult receptor typically is the most sensitive receptor for cancer endpoints. For non-cancer endpoints, the child typically is the most sensitive receptor.

The steps involved in the dermal risk assessment are summarized in Exhibit 5-1.

5.1.2 RISKS FOR ALL ROUTES OF EXPOSURE

Endpoints for assessment of risk for the dermal pathway generally are based on induction of systemic toxicity and carcinogenesis, as they are for the oral and the inhalation routes of exposure. Therefore, the estimate of total risk for exposure to either soil or water contaminants is based on the summation of individual risks for the oral, the inhalation, and the dermal routes.

5.2 UNCERTAINTY ASSESSMENT

The importance of adequately characterizing uncertainty in the risk assessment is emphasized in several U.S. EPA documents (U.S. EPA, 1992b; U.S. EPA, 1995a; U.S. EPA, 1997a; U.S. EPA, 1997b). EPA's 1995 Policy for Risk Characterization calls for greater clarity, transparency, reasonableness and consistency in Agency risk assessments. To ensure transparency and clarity, the Workgroup recommends that an assessment of the confidence, uncertainties, and influence of these uncertainties on the outcome of the risk assessment be presented.

Several sources of uncertainty exist in the recommended approach for estimating exposure and risks from dermal contact with water and soil. Many of these uncertainties are identified in the DEA, Chapter 10. Exposure parameters with highly variable distributions are likely to have a greater impact on the outcome of the risk assessment than those with lower variability. Which exposure parameters will vary the most will depend on the receptor, (i.e., residential adult, commercial adult, adolescent trespasser) and chemical evaluated. For the dermal-soil pathway, the adherence factor and the value used to represent the concentration

Calculation of Dermal Cancer Risk

$$Dermal\ cancer\ risk = DAD \times SF_{ABS} \tag{5.1}$$

where:

Parameter		Dfinition (units)	Default Value
DAD	=	Dermal Absorbed Dose (mg/kg-day)	See Equation 3.1 or Exhibit B-3 (water) See Equations 3.11 and 3.12 (soil)
SF_{ABS}	=	Absorbed cancer slope factor $(mg/kg\text{-}day)^{-1}$	See Equation 4.2

Calculation of Dermal Hazard Quotient

$$Dermal\ hazard\ quotient = \frac{DAD}{RfD_{ABS}} \quad (5.2)$$

where:

Parameter		Definition (units)	Default Value
DAD	=	Dermal Absorbed Dose (mg/kg-day)	See Equation 3.1 or Exhibit B.3 (water) See Equations 3.11 and 3.12 (soil)
RfD_{ABS}	=	Absorbed reference dose (mg/kg-day)	See Equation 4.3

EXHIBIT 5-1

SUMMARY OF DERMAL RISK ASSESSMENT PROCESS

Risk Assessment Process		**Cancer Risk**		**Hazard Index**	
Hazard ID		Section 2		Section 2	
Exposure Assessment	**Child or Adult**	**Water Dose**	**Soil Dose**	**Water Dose**	**Soil Dose**
		Section 3.1, Equations 3.1-3.4	Section 3.2, Equations 3.11/3.12	Section 3.1, Equations 3.1-3.4	Section 3.2, Equations 3.11/3.12
	Age-adjusted Child/Adult SFS_{ADJ}	See Note	Section 3.2.2.5, Equation 3.21	See Note	Section 3.2.2.5, Equation 3.21
Toxicity Assessment		Section 4, SF_{ABS}, Equation 4.2		Section 4, RfD_{ABS}, Equation 4.3	
Risk Characterization		Section 5.1, Equation 5.1 DAD x SF_{ABS}		Section 5.1, Equation 5.2 DAD/RfD_{ABS}	
		Uncertainty Analysis, Section 5.2			

Note: The calculations used in developing the screening tables in Appendix B (Exhibits B-3 and B-4) for the water pathway determined that the adult receptor experiences the highest dermal dose. Therefore, the adult exposure scenario is recommended for screening purposes. However, if an age-adjusted exposure scenario for the dermal route is selected to be consistent with methods for determining the risk of other

in soil are likely to be sensitive variables regardless of the receptor. For the dermal-water pathway, the K_p and the value used to represent the concentration in water are likely to be sensitive variables.

A detailed analysis of the uncertainty associated with every exposure model and exposure variable presented in this guidance is not possible due to insufficient data. RAGS Part E recommends that a qualitative evaluation of key exposure variables and models, and their impact on the outcome of the assessment, be conducted when the database does not support a quantitative Uncertainty Analysis. Below is a discussion of key uncertainty issues associated with the recommended approach for dermal risk assessments in this guidance. Exhibit 5-2 summarizes the degree of

uncertainty associated with the dermal exposure assessment.

5.2.1 HAZARD IDENTIFICATION

Uncertainty is associated with the assumption that the only chemicals of concern in the risk assessment for the dermal-water pathway are those which contribute 10% or more of the dose that is achieved through the drinking water pathway. Although this is a reasonable assumption for exposure assessments in which the drinking water pathway is evaluated, this may result in a slight underestimate of the overall exposure and risk. In addition, the selection of chemicals of concern for the dermal-soil pathway is limited by the availability of dermal absorption values for soil. If soil dermal absorption values are not available, a chemical may be dropped out of the quantitative evaluation of risk, which could potentially result in an underestimate of risk. The recommended default screening value of 10% for semivolatile organic chemicals should limit the degree of underestimation associated with this step of the dermal risk assessment approach.

EXHIBIT 5-2

SUMMARY OF UNCERTAINTIES ASSOCIATED WITH DERMAL EXPOSURE ASSESSMENT

Exposure Factor	High	Medium	Low
COPC selection for dermal-water pathway			X
C_w - exposure point concentration	site-specific, data-dependent		
C_w - ionization state			X
Event duration for showering (t_{event})			X
K_p	X		
C_{soil} - exposure point concentration	site-specific, data-dependent		
Event time for dermal-soil pathway		X	
Surface area (SA) - dermal-soil pathway		X	
Exposure frequency (EF)		X	
Adherence Factor (AF)	X		
Default dermal-soil absorption values and lack of absorption values for other compounds (ABS_d)		X	
Lack of dermal slope factor for cPAHs and other compounds	X		
Lack of info on GI absorption (ABS_{GI})		X	

Above are general statements about the uncertainty associated with each parameter. The actual degree of uncertainty is dependent on the specific chemical, exposure pathway or statistic utilized.

5.2.2 EXPOSURE ASSESSMENT

5.2.2.1 Dermal Exposure to Water – Uncertainties Associated with the Model for DA_{event}

When evaluating uncertainties, it is important to keep in mind that the model used to estimate exposure can contribute significantly to uncertainty. Uncertainty in model predictions arises from a number of sources, including specification of the problem, formulation of the conceptual model, interpretation, and documentation of the results. Although some attempts have been made to validate the model for DA_{event} utilized in this document, a greater effort and more formal process will be necessary before a more accurate assessment of the sources of uncertainty associated with the model can occur. A detailed discussion of the model for DA_{event}, its validation and remaining uncertainties is presented in Appendix A, Sections A.1.4 and A.3.

Concentration in water (C_w). The value used for C_w in the equation for DA_{event} is dependent on several factors, including the method for estimating the exposure point concentration (EPC) (e.g., 95% upper confidence limit of the mean [95%UCL], a maximum concentration, etc.); and the physico-chemical characteristics of the water-borne chemicals. The Superfund program advocates the use of the 95%UCL in estimating exposure to contaminants in environmental media. This policy is based on the assumption that individuals are randomly exposed to chemicals in soil, water, sediment, etc., in a given exposure area and that the arithmetic mean best represents this exposure. To develop a conservative estimate of the mean, a 95% UCL is adopted. However, when data are insufficient to estimate the 95%UCL, any value used for C_w (such as the maximum value or arithmetic mean) is likely to contribute significantly to the uncertainty in estimates of the DA_{event} . The degree to which the value chosen for the EPC contributes to an over- or under-estimate of exposure depends on the representativeness of existing data and the estimator used to represent the EPC.

The bioavailability of a chemical in water is dependent on the ionization state of that chemical, with the non-ionized forms more readily available than the ionized forms. To be most accurate in estimating the dermally absorbed dose, the DA_{event} should be equal to the sum of the DA_{event} values for the non-ionized and ionized species (see Section 3.1.2.2). For most Superfund risk assessments, however, the DA_{event} is most likely to be based on a C_w which is derived directly from a laboratory report. The value presented in a laboratory report represents the total concentration of ionized and non-ionized species and thus does not provide the information necessary to calculate separate DA_{event} values for ionized and non-ionized groups. A slight overestimate of exposure for organic chemicals of low molecular weight is likely to occur if the equations presented in Section 3.1.2.1 are not utilized.

Another factor affecting bioavailability of chemicals in water is the aqueous solubility of the chemical and adsorption to particulate material. Although filtration of water samples in the field has been used to reduce turbidity and estimate the soluble fraction of chemicals in water, the use of data from filtered samples is not recommended for either ingestion or dermal exposure assessments. Therefore, data from unfiltered samples should be used as the basis for estimating the chemical concentration (C_w) for calculating the dermal dose. The use of data from unfiltered samples may tend to overestimate the concentration of chemical that is available for absorption, the extent of the overestimate determined by the magnitude of the difference between the filtered and unfiltered sample. However, water sample collection methods should be employed that minimize turbidity, rather than relying on sample filtration. The impact of this health-protective assumption can be discussed in the Uncertainty Analysis.

In addition, since the concentration of some compounds in water decreases greatly during showering, the impact of volatilization should be considered when estimating C_w for the dermal-water pathway. The exposure analysis for the inhalation pathway should account for compounds which volatilize.

Exposure Time. The recommended default assumptions for exposure time in showering/bathing scenarios are 15 minutes for the central tendency scenario and 35 minutes for the RME scenario. This is consistent with the recommended 50th and 95th percentiles for showering presented in EPA's EFH. If a showering/ bathing scenario exceeded 35 minutes (the recommended central tendency and RME exposure parameters for bathing time are 20 and 60 minutes,

respectively), the default assumption for exposure time might result in a slight underestimate of risk. The degree of underestimation is dependent on the actual showering time.

Permeability coefficients (K_p). Permeability coefficients have been identified as major parameters contributing uncertainty to the assessment of dermal exposure for contaminants in aqueous media (DEA). Two major groups of uncertainties can be identified. The Flynn database, upon which the predictive K_p correlation is derived, includes in vitro data for approximately 90 compounds. The log K_{OW} and MW of these compounds and the experiments designed to measure their K_p values introduce some measures of uncertainty into the correlation coefficients. Using this correlation to predict K_p introduces several other uncertainties. Accuracy of K_{ow} (whether measured or estimated) would affect both the correlation coefficient of Equation 3.8 and the predicted K_p of specific chemicals. Different interlaboratory experimental conditions (e.g., skin sample characteristics, temperature, flow-through or static diffusion cells, concentration of chemicals in solution) influence the value of the resulting measured K_p included in the Flynn database.

Since the variability between the predicted and measured K_p values is no greater than the variability in interlaboratory replicated measurements, this guidance recommends the use of predicted K_p for all organic chemicals. This approach will ensure consistency between Agency risk assessments in estimating the dermally absorbed dose from water exposures. The Flynn database contains mostly smaller hydrocarbons and pharmaceutical drugs which might bear little resemblance to the typical compounds detected at Superfund sites. Predicting K_p from this correlation is uncertain for highly lipophilic and halogenated chemicals with log K_{OW} and MW which are very high or low as compared to compounds in the Flynn database, as well as for those chemicals which are partially or completely ionized. Alternative approaches are recommended for the highly lipophilic and halogenated chemicals, which attempt to reduce the uncertainty in their predicted K_p values.

Another major source of uncertainty comes from the use of K_p obtained from in vitro studies to estimate (in vivo) dermal exposure at Superfund sites. Ths could introduce further uncertainty in the use of estimated K_p in the assessment of exposure and risk from the dermal-water pathway.

5.2.2.2 Dermal Exposure to Soil

Concentration in soil (C_{soil}). The Superfund program advocates the use of the 95% UCL in estimating exposure to contaminants in environmental media. This policy is based on the assumption that individuals are randomly exposed to chemicals in soil, water, sediment, etc., in a given exposure area and that the arithmetic mean best represents this exposure. To develop a conservative estimate of the mean, a 95% UCL is adopted. However, when there are insufficient data to estimate the 95% UCL, any value used for C_{soil} (such as the maximum value or arithmetic mean) is likely to contribute significantly to the uncertainty in estimates of the DA_{event}. The degree to which the value chosen for the EPC contributes to an over- or under-estimate of the exposure is dependent on the representativeness of the existing data and the estimator used to represent the EPC.

Event time (EV). In order to be consistent with assumptions about absorption, the equation for DAD presented in this guidance assumes (by default) that the event time is 24 hours, (i.e., that no washing occurs and the soil remains on the skin for 24 hours). This assumption probably overestimates the actual exposure time for most site-specific exposure scenarios and is likely to result in an overestimate of exposure. The degree to which exposure could be overestimated is difficult to determine without information on absorption rates for each chemical.

Surface area and frequency of exposure. Default adherence values recommended in this guidance are weighted by the surface area exposed and are based on the assumption that adults will be wearing short sleeved shirts, shorts and shoes and that a child will be wearing a short-sleeved shirt, shorts and no shoes. This may not match the year-round exposure scenario assumed to exist at every site. For instance, there is a four-fold difference between the surface area exposed for a residential adult based on the default assumption of clothing worn versus an assumption that an adult is wearing a long-sleeved shirt, and long pants. There is also a four-fold difference between the surface area exposed of a residential child based on the default assumption of clothing worn versus an assumption that

a child is wearing a long-sleeved shirt, long pants, shoes and socks. The value chosen for surface area can introduce a moderate degree of uncertainty into exposure and risk estimates. Risk assessors may need to adjust defaults depending upon site conditions such as climate and activity patterns.

The value chosen for frequency can also introduce moderate amounts of uncertainty into exposure and risk assessment estimates. For instance, it is assumed that a resident comes into contact with residential soils 350 days/yr. If the actual frequency is significantly less (for instance one day per week, equivalent to 52 days/yr), a seven-fold difference occurs, which directly impacts exposure and risk estimates.

Adherence factors. Although RAGS Part E provides dermal adherence factors for several different types of receptors, the conditions at a particular site may not match the conditions in the study upon which the default dermal adherence factor is based, (i.e., specific activity, clothing worn, soil type, soil moisture content, exposure duration, etc). For example, Kissel, et al. (1996) has found that finer particles adhere preferentially to the hands unless soils are greater than 10% moisture. Some studies have found that soil particles greater than 250 microns do not adhere readily to skin. Thus the soil type, including moisture content, can affect the adherence of soil. In addition, the specific activity which occurs in the site-specific exposure scenario may not directly match the activities for which adherence factors are available in this guidance. All of these factors can introduce significant uncertainties into the exposure assessment. Each of these factors should be carefully evaluated in each risk assessment conducted for the dermal pathway.

Dermal-soil absorption factors. The amount of chemical absorbed from soil is dependent on a number of chemical, physical and biological factors of both the soil and the receptor. Examples of factors in soil which can influence the amount of chemical that is available to be absorbed include; soil type, organic carbon content, cation exchange capacity, particle size, temperature, pH, etc. For example, increasing particle size has been found to correspond with decreased absorption across the skin for some chemicals. Chemical factors which can affect absorption include lipid solubility, chemical speciation, aging of the chemical, etc. Physical factors which can impact absorption include soil loading rate, surface area exposed to soil, soil contact time and soil adherence. For example, fraction absorbed from soil is dependent on the soil loading. In general, as the soil loading increases, the fraction absorbed should be constant, until one gets above a critical level at which the skin surface is uniformly covered by soil (i.e., the mono-layer). Since nearly all existing experimental determinations of fraction absorbed have been conducted above the mono-layer, the actual fraction absorbed could be larger than experimentally determined. Biological factors which can affect absorption include diffusivity of skin, skin blood flow, age of the receptor, etc. The exact relationship of all of these factors to dermal absorption is not known. Thus, there is uncertainty in the default dermal absorption factors. This discussion should be presented in the risk assessment, but until more is understood quantitatively about this effect, adjustment of the dermal-soil absorption factors is not warranted.

Default Dermal Absorption Values for Semivolatile Organic Chemicals. This guidance identifies a default dermal absorption value of 10% for semivolatile organic compounds as a class. This suggested value is based on the assumption that the observed experimental values presented in Exhibit 3-4 are representative of all semivolatile organic compounds for which measured dermal-soil absorption values do not exist. Chemicals within classes vary widely in structure and chemical properties. The use of default dermal absorption values based on chemical class can introduce uncertainties into the risk assessment which can either over- or under-estimate the risk.

Lack of dermal-soil absorption values. The ability to quantify the absorption of contaminants from exposure to soil is limited. Chemical-specific information is available for only a few chemicals. For most chemicals, no data are available, so dermal exposures have not been quantified. This lack of data results in the potential underestimation of total exposure and risk. The degree of the underestimation is dependent on the chemical being evaluated.

5.2.3 TOXICITY ASSESSMENT

Oral reference doses and slope factors for dermal exposures. Quantitative toxicity estimates for dermal exposures have not been developed by EPA.

Therefore, oral reference doses and oral cancer potency factors are used to assess systemic toxicity from dermal exposures. The dermal route of exposure can result in different patterns of distribution, metabolism, and excretion than occur from the oral route. When oral toxicity values for systemic effects are applied to dermal exposures, uncertainty in the risk assessment is introduced because these differences are not taken into account. Since any differences between oral and dermal pathways would depend on the specific chemical, use of oral toxicity factors can result in the over- or underestimation of risk, depending on the chemical. It is not possible to make a general statement about the direction or magnitude of this uncertainty.

Lack of a dermal slope factor for polynuclear aromatic hydrocarbons (PAHs) and other chemicals. This guidance focuses on the expected systemic effects of dermal exposure from chemicals in soil and water. EPA does not have recommended toxicity values for the adverse effects that can occur at the skin surface. This lack of dermal toxicity values is considered to be a significant gap in the evaluation of the dermal pathway, particularly for carcinogenic PAHs. The statement in RAGS claiming that "it is inappropriate to use the oral slope factor to evaluate the risks associated with exposure to carcinogens such as benzo(a)pyrene, which causes skin cancer through direct action at the point of application" should not be interpreted to mean that the systemic effects from exposure to dermally active chemicals should not be evaluated. In fact, there is a significant body of evidence in the literature to generate a dose-response relationship for the carcinogenic effects of PAHs on the skin. In addition, PAHs have also been shown to induce systemic toxicity and tumors at distant organs. For these reasons, the lack of dermal toxicity values may significantly underestimate the risk to exposure to PAHs and potentially other compounds in soil. Until dermal dose-response factors are developed, EPA recommends that a quantitative evaluation be conducted for systemic effects of PAHs and other compounds and that a qualitative evaluation be conducted for the carcinogenic effects of PAHs and other compounds on the skin.

5.2.4 RISK CHARACTERIZATION

Lack of information for GI absorption. One issue in the dermal-soil risk assessment approach presented in this guidance is how would the route comparison (i.e., oral to dermal) change if the GI tract absorption fraction were much less than the assumed 100%. As discussed in Chapter 10 of the DEA, cancer slope factors are intended to be used with administered dose. Since dermal doses are absorbed, it is necessary to convert the SF to an absorbed basis which can be done in an approximate way by dividing it by the GI tract absorption fraction. When ABS_{GI} is high, adjustment of the SF to an absorbed dose is not as important and the earlier conclusions for when the dermal dose exceeds the ingested dose do not change. However, when ABS_{GI} is low, the adjustment of the SF to an absorbed dose can substantially increase the importance of the dermal route relative to the ingestion route and it is important to consider. In the absence of information on gastrointestinal absorption, the risk characterization for the dermal pathway has used unadjusted reference doses and slope factors. This may result in under-estimation of risk for dermal exposures to both soil and water.

CHAPTER 6

CONCLUSIONS/RECOMMENDATIONS

6.1 SUMMARY

The following summary presents the major points made in each chapter of this guidance.

Hazard Identification

- For the dermal-water pathway, only those chemicals which contribute to more than 10% of the dose from the oral (drinking water) pathway should be considered important enough to carry through the risk assessment.

- For the dermal-soil pathway, the limited availability of dermal absorption values is expected to result in a limited number of inorganic contaminants being considered in a quantitative risk assessment. An important decision for the risk assessor is whether the default value of 10% dermal absorption from soil, for all organic compounds without specific absorption values, should be applied to a quantitative risk assessment.

Exposure Assessment

- Since the K_p parameter has been identified as one of the major parameters contributing to uncertainty in the assessment of dermal exposures to contaminants in aqueous media, it is important that risk assessments be consistent when estimating this parameter. Since the variability between the predicted and measured K_p values is no greater than the variability in inter-laboratory replicated measurements, this guidance recommends the use of predicted K_p values (Appendices A and B) based on the equations in Chapter 3. However, there are some chemicals (Exhibit A-1) that fall outside the Effective Prediction Domain for determining K_p, particularly those with a high molecular weight and high K_{ow} values. To address these chemicals, a fraction absorbed (FA) term should be applied to account for the loss of chemical due to the desquamation of the outer skin layer and a corresponding reduction in the absorbed dermal dose. For halogenated chemicals, Equation 3.8 could underestimate K_p due to the lower ratio of molar volume related to molecular weight for these halogenated compounds as compared to those included in the Flynn database. A new K_p correlation based on molar volume and log K_{ow} will be explored.

- This guidance presents recommended default exposure values for all variables for the dermal-water and dermal-soil pathways in Exhibits 3-2 and 3-5, respectively.

- For dermal-water exposures, the entire skin surface area is assumed to be available for exposure when bathing and swimming occurs. The assessor should note that a wading scenario may result in less surface area exposed. For dermal-soil exposures, clothing is expected to limit the extent of exposed surface area. For the adult resident, the total default surface area should include the head, hands, forearms and lower legs. For a residential child the default surface area should include the head, hands, forearms, lower legs and feet. For an adult commercial/industrial worker, the total default surface area should include the head, hands and forearms.

- During typical exposure scenarios, more soil is dermally contacted than is ingested. The default soil adherence factor (AF) for RME adult residential activities (0.07 mg/cm^2) should be based on the central tendency value for a high-end soil contact activity (e.g., a gardener). The default AF value for a RME child resident (0.2 mg/cm^2) should be based on both the high end estimate for an average soil contact activity (i.e., children playing in dry soil) and the central tendency AF estimates for a high-end soil contact-intensive activity (i.e., children playing in wet soil). The default AF value for a commercial/ industrial adult worker (0.2 mg/cm^2) should be based on the central tendency estimate for a high-end soil contact activity (i.e., utility worker).

- The contribution of dermal absorption of chemicals

from soils to the systemic dose generally is estimated to be more significant than direct ingestion for those chemicals which have a soil absorption fraction exceeding about 10%.

- Dermal-soil absorption values for ten compounds are provided in this guidance. Screening absorption values are provided for semi-volatile organic compounds as a class. No screening values are provided for inorganic compounds, due to the lack of sufficient data on which to base an appropriate default screening level for inorganics other than arsenic and cadmium. As new information on dermal absorption from soil becomes available, this guidance will be updated.

Toxicity Assessment

- Before estimating risk from dermal exposures, the toxicity factor should be adjusted so that it is based on an absorbed dose. Usually, adjustments of the toxicity factor are only necessary when the GI absorption of a chemical from a medium similar to the one employed in the critical study is significantly less than 100% (i.e., 50%). Recommended GI absorption values are presented in Exhibit 4-1.

6.2 EXPOSURES NOT INCLUDED IN CURRENT DERMAL GUIDANCE

- This guidance does not explicitly recommend exposure parameters for contact with contaminated sediment. This exclusion is due to the high degree of variability in sediment adherence and duration of sediment contact with the skin. However, information is included in the guidance document that would allow a risk assessor to assess sediment exposure on a site-specific basis.

- This guidance does not specifically address dermal toxicity, either acute or chronic. The dermal dose derived with this methodology provides an estimate of the contribution of the dermal pathway to the systemic dose. The exclusion of dermal toxicity should be considered an uncertainty issue that could underestimate the total risk.

- Current studies suggest that dermal exposure may be expected to contribute no more than 10% to the total body burden of those chemicals present in the vapor phase. Therefore, this guidance does not include a method for assessing dermal absorption of chemicals in the vapor phase, with the assumption that inhalation will be the major exposure route for vapors. An exception may be workers wearing respiratory protection but not chemical protective clothing.

- The methodology described in this guidance does not cover the exposure associated with dermal contact with contaminated surfaces.

6.3 RECOMMENDATIONS

- The dermal risk guidance uses a mathematical model to predict absorption and risk from exposures to water. Contaminants for which there are sufficient data to predict dermal absorption with acceptable confidence are said to be within the model's effective predictive domain (EPD). Although the methodology can be used to predict dermal exposures and risk to contaminants in water outside the EPD, there appears to be greater uncertainty for these contaminants. OSWER and the workgroup, which developed this guidance, do not recommend that the model be used to quantify exposure and risk to contaminants in water that are outside the EPD in the "body" of the risk assessment. Rather, it is recommended that such information be presented in the discussion of uncertainty in the risk assessment. OSWER and the workgroup recommend that experimental studies to generate data for these chemicals be planned and completed during remedial investigations on Superfund sites where dermal exposures to these chemicals may occur, using site-specific exposure conditions as appropriate.

- OSWER and the dermal workgroup also encourage experiments to generate additional data on the soil dermal absorption fraction (see Appendix E). The dermal workgroup will work with regional risk assessors on the development of the study designs and will review study results submitted to it. Additional details, recommendations, and a few references are provided in Appendix E.

- The Superfund Dermal Workgroup will be available for consultation on dermal risk assessment

issues. It is recommended that the Workgroup be consulted before dermal absorption values other than those listed in Exhibit 3-4 or in Appendix B are used in quantitative risk assessments. In the future, risk assessors are encouraged to provide the Workgroup with new information regarding chemical-specific studies of dermal absorption from soil, or water, as well as any other exposure factors for the dermal pathway.

- Areas where additional research would provide much needed information for addressing the dermal exposure pathway include: 1) quantification of dermal absorption from soil (percent absorbed) for high priority compounds, including inorganic compounds, using both in vivo and in vitro techniques, 2) determination of the effect of soil type/size on bioavailability of soil-bound compounds, and 3) methods for assessing risks associated with direct dermal toxicity of chemical exposures.

- A Peer Consultation Workshop on Issues Associated with Dermal Exposure and Uptake was held December 10-11, 1998. The Workshop was sponsored by the EPA Risk Assessment Forum . A report summarizing the proceedings and recommendations of the Workshop can be obtained from the Risk Assessment Forum Web site (http://www.epa.gov/ncea/raf/rafrprts.htm).

  Many of the Workshop recommendations for immediate action were incorporated into this guidance document. EPA is considering the development of a dermal database to be located on the EPA Web site that would provide information on chemico-physical properties, soil absorption and permeability coefficients of specific chemicals and information on dermal exposure parameters. Additional long-term recommendations, particularly the development of a unified model for assessing dermal exposure from multiple media (e.g., water and soil), will be considered for future research initiatives.

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APPENDIX A

WATER PATHWAY

General guidance for evaluating dermal exposure at Superfund sites is provided in Risk Assessment Guidance for Superfund (RAGS), Human Health Evaluation Manual (HHEM), Part A (U.S. EPA, 1989a). *Dermal Exposure Assessment Principles and Applications* (DEA) (U.S. EPA, 1992a) details procedures for estimating permeability coefficients of toxic chemicals and for evaluating the dermal absorbed dose. Section A.1 summarizes equations to evaluate the absorbed dose per event (DA_{event}) in Equations 3.2 and 3.3 and other equations from the DEA. It also updates the regression model to predict the water permeability coefficient for organics. Statistical analysis of the regression equation provides the range of octanol/water partition coefficients (K_{ow}) and molecular weights (MW) where this regression model could be used to predict permeability coefficients (Effective Prediction Domain - EPD), as recommended by the Science Advisory Board review in August 1992. Predictive values of the dermal permeability coefficient (K_p) for over 200 compounds are provided with the 95% lower and upper confidence level in Appendix B (Exhibit B-2).

For chemicals with MW and K_{ow} outside the EPD, a model for predicting the fraction absorbed dose (FA) is proposed for those chemicals with high K_{ow}, taking into account the balance between the increased lag time of these chemicals in the stratum corneum and the desquamation of the skin during the absorption process; the consequence of which results in a net decrease in total systemic absorption.

Because the variability between the predicted and measured K_p values is no greater than the variability in interlaboratory replicated measurements, this guidance recommends the use of predicted K_p for all organic chemicals. This approach will ensure consistency between Agency risk assessments in estimating the dermal absorbed dose from water exposures. The Flynn database (Flynn, 1990) contains mostly hydrocarbons which might bear little resemblance to the typical compounds detected at Superfund sites. Predicting K_p from this correlation is uncertain for highly lipophilic and halogenated chemicals with log K_{ow} and MW values which are very high or low as compared to compounds in the Flynn database, as well as compounds for those chemicals which are partially or completely ionized. Alternative approaches are recommended for the highly lipophilic and halogenated chemicals, which attempt to reduce the uncertainty in their predicted K_p. Complete calculation of dermal absorbed dose (DAD) for the showering scenario using default assumptions is performed for over 200 compounds, and included in Appendix B (Exhibit B-3). For inorganics, Section A.2 provides permeability coefficients of several metals. Section A.3 discusses the uncertainty of the parameters used in the estimation of the dermal dose. Section A.4 provides the assumptions and calculations for the screening provided in Chapter 2:

Hazard Identification. Section A.5 summarizes the calculation procedures as well as the instructions for using the spreadsheets, which are provided on the Internet at the following URL: http://www.epa.gov/superfund/programs/risk/ragse/index.htm

A.1 DERMAL ABSORPTION OF ORGANIC COMPOUNDS

A.1.1 ESTIMATION OF K_p FOR ORGANIC COMPOUNDS

As discussed in DEA, the thin outermost layer of skin, the stratum corneum, is considered to be the main barrier to percutaneous absorption of most chemicals. The stratum corneum can be described as sheets of dead, flattened cells containing the protein keratin, held together by a lipoidal substance. Numerous studies, presented in the DEA, show that when this stratum corneum serves as the limiting barrier to diffusion through the skin, the permeability coefficient of a compound in water through the skin can be expressed as a function of its oil/water partition coefficient (K_{ow}, or most often, log K_{ow}), and its molecular weight (MW). This correlation was presented in the DEA as the Potts and Guy's equation (DEA: Equation 5.8), obtained based on the Flynn database (Flynn, 1991), shown in Exhibit B-1 of Appendix B.

In RAGS Part E, the Potts and Guy correlation has been refined to the following equation by excluding the three in vivo experimental data points in DEA, Table 5-8: ethyl benzene, styrene, and xylene, to limit the Flynn database to in vitro studies using human skin. The new algorithm results in Equation 3.8.

$$\log K_p = -2.80 + 0.66 \log K_{ow} - 0.0056\, MW \qquad (r^2 = 0.66) \qquad (3.8)$$

where:

Parameter		Definition (units)	Default Value
K_p	=	Dermal permeability coefficient of compound in water (cm/hr)	Chemical-specific, see Appendix B
K_{ow}	=	Octanol/water partition coefficient (dimensionless)	Chemical-specific, see Appendix B
MW	=	Molecular weight (g/mole)	Chemical-specific, see Appendix B

As can be seen from Equation 3.8, the molecular weight and polarity described by the octanol/water partition coefficient are the sole predictors of K_p. The above equation containing predicted values of K_p was evaluated against actual experimentally determined values for K_p and was found to correlate reasonably well, with few exceptions that may be attributed to experimental or analytical error. In DEA, it was recommended that the predicted values be used over the experimental measurements for the following two reasons: 1) for consistency with chemicals without an experimental measurement of K_p and, 2) to minimize inter-laboratory differences. Recently, Vecchia (1997) examined almost twice as many permeability coefficient values as those in the Flynn data set and found that replicated experimental measurements often vary by one to two orders of magnitude. This finding confirms the current continued recommendation that, for organics in water, the predicted values for K_p obtained from the above algorithm be used instead of actual measured values.

To determine the range of MW and log K_{ow}, where Equation 3.8 would be valid for extrapolation to other chemicals given that the physico-chemical properties used in the K_p correlation (MW and log K_{ow}) are not completely independent of each other, the following Effective Prediction Domain (EPD) is determined using Mandel's approach (Mandel, 1982, 1985) for collinear data. This approach uses experimental data points in the derivation of the regression equation (here, the Flynn database, presented in Exhibit B-1) to determine the specific ranges of MW and log $K_{ow,}$ where the predictive power of the regression equation would be valid. This analysis uses the software MLAB (Civilized Software, Bethesda, MD, 1996).

Using Mandel's analysis (Mandel, 1985), the following boundaries of MW and log K_{ow} for the above regression correlation were determined and are presented by Equations 3.9 and 3.10.

$$-0.06831 \leq 5.103 \times 10^{-4}\, MW + 0.05616 \log K_{ow} \leq 0.5577 \qquad (3.9)$$

$$-0.3010 \leq -5.103 \times 10^{-4}\, MW + 0.05616 \log K_{ow} \leq 0.1758 \qquad (3.10)$$

where:

Parameter		Definition (units)	Default Value
K_{ow}	=	Octanol/water partition coefficient (dimensionless)	Chemical-specific, see Appendix B
MW	=	Molecular weight	Chemical-specific, see Appendix B

The points defining the EPD are shown in Exhibit A-1. The axes shown in the middle of the exhibit are obtained by translating the original axes (defined at 0 for both MW and log K_{ow}) to the center of the Flynn data set. The actual boundaries of the EPD are constructed by rotating these axes by 45°, then by drawing lines through the EPD points parallel to the new axes. All of Flynn's data would fall within the EPD, using the above exact solutions given by Equations 3.9 and 3.10.

From the list of 200 common pollutants, those which are outside the EPD, as defined by Equations 3.9 and 3.10, are summarized in Exhibit A-2 . The compound characteristics for which the modified Potts and Guy correlation would not apply would be those with a combination of log K_{ow} and MW satisfying those two equations.

The permeability coefficients of two classes of chemicals with very low K_{ow} and very high K_{ow} have been known not to correlate well with the log K_{ow} (Leahy, 1990). Correlations like those in Equation 3.8 are based on the assumption that chemical absorption is primarily through a dissolution-diffusion process in the lipid material of the stratum corneum. Chemicals with low K_{ow} will have limited permeability through the lipid material of the stratum corneum, and penetration by other routes (e.g., appendages such as sweat glands or hair follicles or through regions of the stratum corneum with even minor damage) may contribute significantly. Permeability coefficients reported in the Flynn data set are measured at steady-state (i.e., $t_{event} > 2.4\ \tau_{event}$). Consequently, for chemicals with very high log K_{ow}, experimental values of permeability coefficients will include contributions of the viable epidermis.

Exhibit B-2 summarizes the predicted K_p for over 200 organic chemicals. Results of the current EPD analysis points out that for about 10% of those chemicals, this prediction would not be valid, according to the current use of Flynn's data set as the basis for the correlation equation between K_p and log K_{ow} and MW. Strictly, chemicals with very large and very small K_{ow} are outside of the EPD of Equation 3.8. Although large variances in some data points contributed to the definition of the EPD, it is defined primarily by the properties of the data used to develop Equation 3.8. With no other data presently available for chemicals with very large and very small K_{ow}, it is appropriate to use Equation 3.8 as a preliminary estimate of K_p.

Exhibit A-1

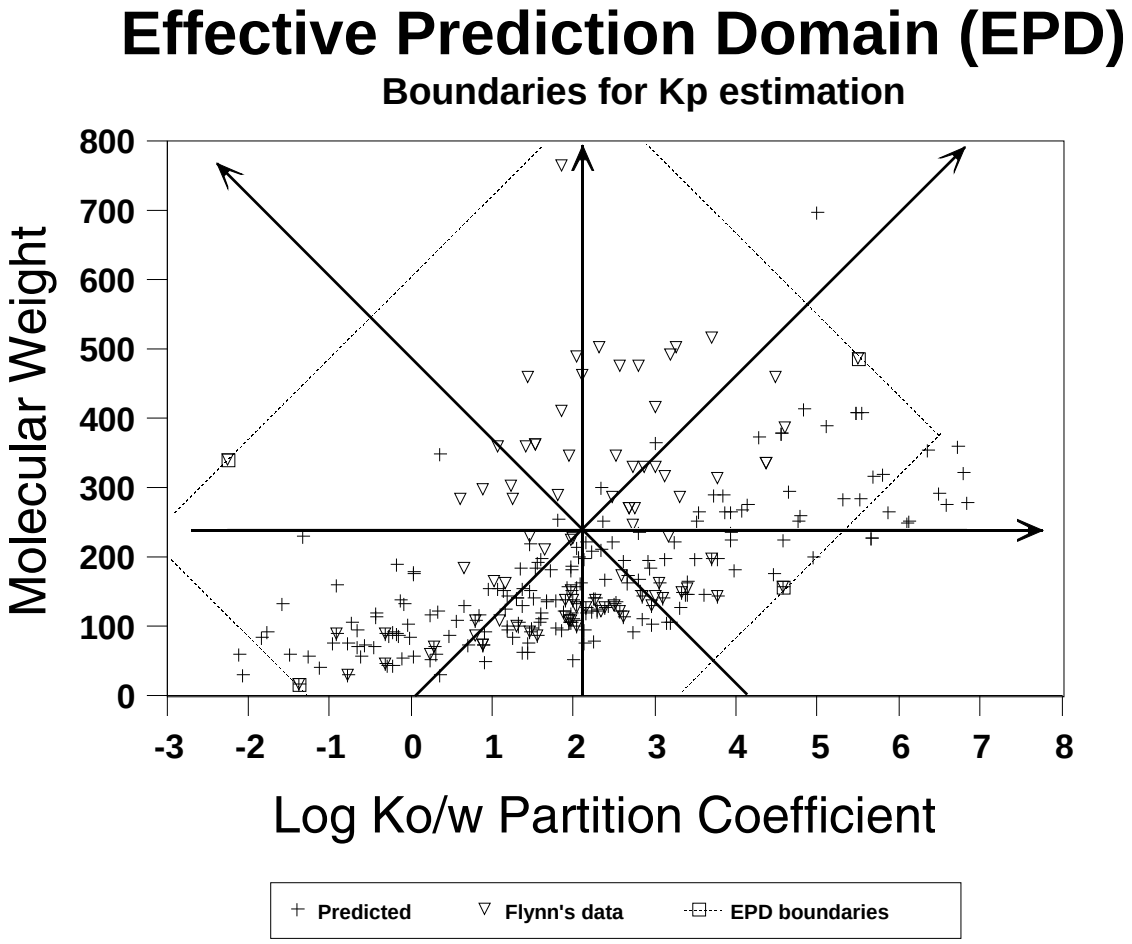

Effective Prediction Domain (EPD)
Boundaries for Kp estimation
Molecular Weight
800
700
600
500
400
300
200
100
0
-3
-2
-1
0
1
2
3
4
5
6
7
8
Log Ko/w Partition Coefficient
Predicted
Flynn's data
EPD boundaries

EXHIBIT A-2

COMPOUNDS FROM APPENDIX B WITH PERMEABILITY COEFFICIENTS OUTSIDE OF THE EFFECTIVE PREDICTION DOMAIN OF THE MODIFIED POTTS AND GUY CORRELATION

Log K_{ow} < -2			Log K_{ow} > 4		
Chemicals	Log K_{ow}	MW	Chemicals	Log K_{ow}	MW
Urea	-2.11	60	Benzo-a-anthracene	5.66	228
Hydrazine H-sulfate	-2.07	32	Benzo-a-pyrene	6.10	250
			Benzo-b-fluoranthene	6.12	252
			Chrysene	5.66	228
			DDT	6.36	355
			Dibenzo(a,h)anthracene	6.84	278
			Indeno(1,2,3-c,d)pyrene	6.58	276.3
			PCB-chlorobiphenyl	6.50	292
			PCB-hexachlorobiphenyl	6.72	361
			Phenanthrene	4.46	178.2
			Pentachlorophenol	5.86	266
			TCDD	6.80	322
			Tris(2,3-dibromopropyl) phosphate	4.98	697.6

[1]Range was approximated from properties of the chemicals identified by the EPD analysis, but do not define the EPD.

A.1.2 CALCULATION OF OTHER PARAMETERS IN DA_{event}

The two-compartment model used to represent the skin (recommended in DEA) is unchanged in RAGS Part E, although all equations used in the evaluation of the dermal absorbed dose (DA_{event}) are updated, according to the latest literature [Cleek and Bunge (1993) and Bunge and Cleek (1995)]. At short exposure durations, Equation 3.2 specifies that the DA_{event} is proportional to the stratum corneum permeability coefficient (K_p) and the contribution of the permeability of the viable epidermis is not included. Significantly, B (the ratio of the permeability coefficient of a compound through the stratum corneum relative to its permeability coefficient across the viable epidermis) does not appear in the equation for short exposure duration [Eq 3.2] because the absorbing chemical has not had enough time to travel across the stratum corneum. Consequently, for short exposure durations, the amount of chemical absorbed depends only on the permeability coefficient (K_p) of the stratum corneum (SC), the outermost skin layer. For longer exposure durations, Equation 3.3 specifies that the DA_{event} is restricted by the permeability of the viable epidermis and the stratum corneum, and thus B, the ratio of the permeability of the stratum corneum to that of the epidermis, appears in Equation 3.3.

The following presentation and Equations A.1 to A.8 summarize and update the equations from those in the DEA, Chapters 4 and 5, for estimating all parameters needed to evaluate DA_{event}. For a detailed explanation and derivation of the equations, please refer to DEA, Chapters 4 and 5, and Cleek and Bunge (1993) and Bunge and Cleek (1995).

The dimensionless parameter B expresses the relative contribution of the permeability coefficient of the compound in the stratum corneum (K_p, estimated from Equation 3.8) and its permeability coefficient in the viable epidermis. Bunge and Cleek (1995) discussed four different methods to estimate B, and recommended the use of Equation A.1, as adopted in this document.

The complete derivation of Equation A.1 is presented in Bunge and Cleek (1995). As defined, B is a function of the permeability coefficient (K_p), which is a function of molecular weight (MW) and the partition coefficient (log K_{ow}) given by Equation 3.8. Exhibit A-3 shows how B changes with MW and log K_{ow}.

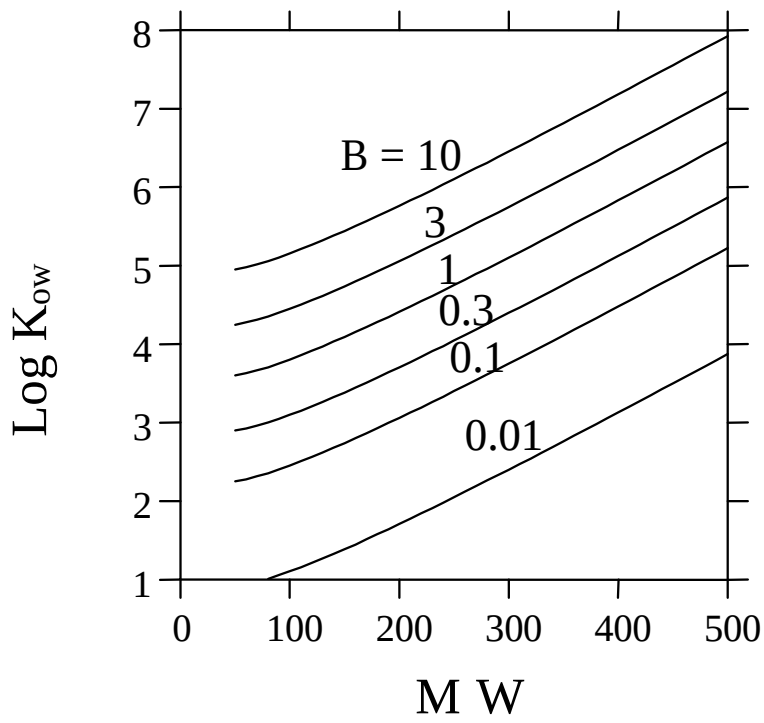
$$B = \frac{K_p}{K_{p,ve}} \simeq K_p \frac{\sqrt{MW}}{2.6} \ (as\ an\ approximation) \qquad (A.1)$$

where:

Parameter		Definition (units)	Default Value
B	=	Dimensionless ratio of the permeability coefficient of a compound through the stratum corneum relative to its permeability coefficient across the viable epidermis (ve)	–
$K_{p,ve}$	=	Steady-state permeability coefficient through the viable epidermis (ve) (cm/hr)	$K_{p,ve} = K_{ew}D_e/L_e$, $K_{ew} = 1$ assuming epidermis behaves essentially as water; $L_e = 10^{-2}$ cm, $D_e = 7.1x10^{-6}$/MW cm^2/s assuming $D_e=10^{-6}$ cm^2/s when MW = 50 (Bunge and Cleek, 1995)
K_p	=	Dermal permeability coefficient in water (cm/hr)	Equation 3.8
MW	=	Molecular weight (g/mole)	Chemical-specific
K_{ew}	=	Equilibrium partition coefficient between the epidermis and water for the absorbing chemical (dimensionless)	Chemical-specific
D_e	=	Effective diffusivity of the absorbing chemical in the epidermis (cm^2/hr)	Chemical-specific
L_e	=	Effective thickness of the epidermis (cm)	10^{-2}

EXHIBIT A-3

EFFECTS OF MW AND LOG K_{ow} ON B



Using the same approach as in DEA, Equations 5.13, A.2 and A.3 are derived to estimate D_{sc}/l_{sc} (cm/hr).

$$\log \frac{D_{sc}}{l_{sc}} = -2.80 - 0.0056\ MW \tag{A.2}$$

or:

$$\frac{D_{sc}}{l_{sc}} = 10^{(-2.80\ -\ 0.0056\ MW)} \tag{A.3}$$

where:

Parameter		Definition (units)	Default Value
D_{sc}	=	Effective diffusion coefficient for chemical transfer through the stratum corneum (cm^2/hr)	Chemical-specific
l_{sc}	=	Apparent thickness of stratum corneum (cm)	10^{-3} cm
MW	=	Molecular weight (g/mole)	Chemical-specific

Assuming $l_{sc} = 10^{-3}$ cm as a default value for the thickness of the stratum corneum, t_{event} can be evaluated using Equation A.4:

$$\tau_{event} = \frac{l_{sc}^2}{6\ D_{sc}} = 0.105 \times 10^{(0.0056\ MW)} \tag{A.4}$$

where:

Parameter		Definition (units)	Default Value
τ_{event}	=	Lag time per event (hr/event)	Chemical-specific
D_{sc}	=	Effective diffusion coefficient for chemical transfer through the stratum corneum (cm^2/hr)	Chemical-specific
l_{sc}	=	Apparent thickness of stratum corneum (cm)	10^{-3}
MW	=	Molecular weight (g/mole)	Chemical-specific

Calculate t^*:

$$If\ B \leq 0.6,\ then\ t^* = 2.4\ \tau_{event} \tag{A.5}$$

$$If\ B > 0.6,\ then\ t^* = 6\ \tau_{event}\ (b - \sqrt{b^2 - c^2}) \tag{A.6}$$

$$b = \frac{2\ (1 + B)^2}{\pi} - c \tag{A.7}$$

$$c = \frac{1 + 3B + 3B^2}{3(1 + B)} \tag{A.8}$$

where:

Parameter		Definition (units)	Default Value
B	=	Dimensionless ratio of the permeability coefficient of a compound through the stratum corneum relative to its permeability coefficient across the viable epidermis (ve) (dimensionless).	Chemical-specific
t^*	=	Time to reach steady-state (hr)	Chemical-specific
τ_{event}	=	Lag time per event (hr/event)	Chemical-specific
D_{sc}	=	Effective diffusion coefficient for chemical transfer through the stratum corneum (cm^2/hr)	Chemical-specific
l_{sc}	=	Apparent thickness of stratum corneum (cm)	10^{-3}
b, c	=	Correlation coefficients which have been fitted to the Flynn's data to give Equation 3.8	

All the above calculations are performed for over 200 chemicals for a defined default scenario (adults showering once a day for 35 minutes) with the results tabulated in Appendix B. These calculations are also provided in two MS Excel spreadsheets: one for organics (ORG04_01.XLS), and one for inorganics

(INORG04_01.XLS), which will be available at the RAGS E website: http://www.epa.gov/superfund/programs/risk/ragse/index.htm or http://www.epa.gov/oswer/riskassessment/.

A.1.3. MODEL ADJUSTMENT FOR LIPOPHILIC COMPOUNDS OUTSIDE EPD

The above model assumes that all chemicals absorbed into the skin during the exposure event (t_{event}) would eventually be absorbed into the systemic circulation, with the stratum corneum being the main barrier for most chemicals. For highly lipophilic chemicals, the viable epidermis can be a significant barrier for chemical transfer from the stratum corneum to the systemic circulation. When this occurs, the relative rate of desquamation of the stratum corneum and cell proliferation rate at the base of the viable epidermis contribute to a net decrease in the total amount of absorbed chemical. For similar reasons, stratum corneum desquamation can reduce the amount of absorption for chemicals that are not highly lipophilic but large enough (high MW) that penetration through the stratum corneum is slow (i.e., lag times are long).

A mathematical model was developed by Reddy et al. (2000) to account for the loss of chemical available for systemic absorption due to the desquamation of the outer layer of the stratum corneum. This model accounts for the relative rates of epidermal turnover and percutaneous penetration. Using the assumptions that the average turnover time of the stratum corneum is 14 days (t_{sc} ~ 14 days or 336 hours), while that of the viable epidermis is 28 days (twice the time for the stratum corneum to turnover) in normal skin, Reddy et al. (2000) solved a set of partial differental mass balances for the stratum corneum and viable epidermis. After solving these equations, they calculated the fraction of the chemical that is ultimately absorbed (FA), allowing for losses by stratum corneum desquamation. Reddy et al. (2000) showed that FA is almost independent of t_{event}. However, FA depends strongly on the chemical's lipophilic characteristic and molecular weight as expressed in the B parameter and the lag time (τ_{event}), as illustrated in Exhibit A-4. A large number of the chemicals outside the EPD fall into this category, as well as a few chemicals within the EPD, especially those with high molecular weight. Given B and τ_{event}, FA values can be obtained from Exhibit A-5. FAs are included in Exhibit B-3 and in the spreadsheet ORG04_01.XLS. There are only a small number of chemicals that have a FA value < 0.5, but since most of those are highly lipophilic molecules that are often found in Superfund sites, the Dermal Workgroup is recommending that FA should be included in the calculation of DAD when applicable.

A.1.4 MODEL VALIDATION

Two papers in the literature have offered an attempt to validate the dermal absorption model (from now on referred to as the DEA model) presented in Section 3.1 for organics: McKone (1993) and Pirot et al. (1997).

McKone (1993) used experimentally measured and previously reported (Jo et al., 1990) ratios of chloroform concentrations in inhaled air to tap-water concentration to evaluate the exposure model predictions. Particular attention was given to the implied dermal uptake measured by these experiments and to whether this is consistent with the recommended value for skin uptake of chloroform calculated by the DEA model. The Workgroup finds that the K_p implied by the Jo et al. (1990) shower data is 2.4 times higher than the value predicted by McKone and Howd (1992) and 6.7 times higher than the value predicted by the DEA model; and that the DA_{event} implied by the Jo et al., (1990) shower data is 2.6 times higher than the value predicted by McKone and Howd (1992) and 5 times higher than the value predicted by the DEA model. Also found was that both predictive models appear to have lag time estimates higher than is consistent with the Jo et al. (1990) shower data.

The Workgroup concludes that these results do not likely indicate any inherent flaws in the two predictive models, but instead reveal that models are only as reliable as the data they employ, and that a more formal process to assess sources of uncertainty is needed. For example, McKone and Howd (1992) have shown that the estimation error in their prediction of K_p has a geometric standard deviation (GSD) of three and they have estimated the GSD in the DEA model prediction of K_p as 3.8, confirmed as given by the 95% confidence level (95% CL) in Exhibit B-2. If this estimation error is applied to the measurement errors in the Jo et al. (1990a) experiments, the predicted and experimentally implied skin uptake parameters could reasonably differ from each other by factors of 3 to 7.

More recently, Pirot et al. (1997) have used attenuated total reflectance Fourier Transform infrared spectroscopy to quantify in vivo the uptake of 4-hydroxybenzonitrile by human stratum corneum. Results of this analysis were used to construct a time profile of the cumulative amount of 4-hydroxybenzonitrile permeating the skin as a function of time. The authors show that the calculated permeability coefficient ($K_p \sim 3.6 \times 10^{-3}$ cm/hr) based on an assumed value of $l_{sc} = 1.5 \times 10^{-2}$ cm, agrees well with that predicted by Equation 3.8, which yields a $K_p = 6.8 \times 10^{-3}$ cm/hr.

EXHIBIT A-4

FRACTION ABSORBED (FA) AS A FUNCTION OF SPECIFIC COMBINATIONS OF B AND τ_{event}/t_{sc}

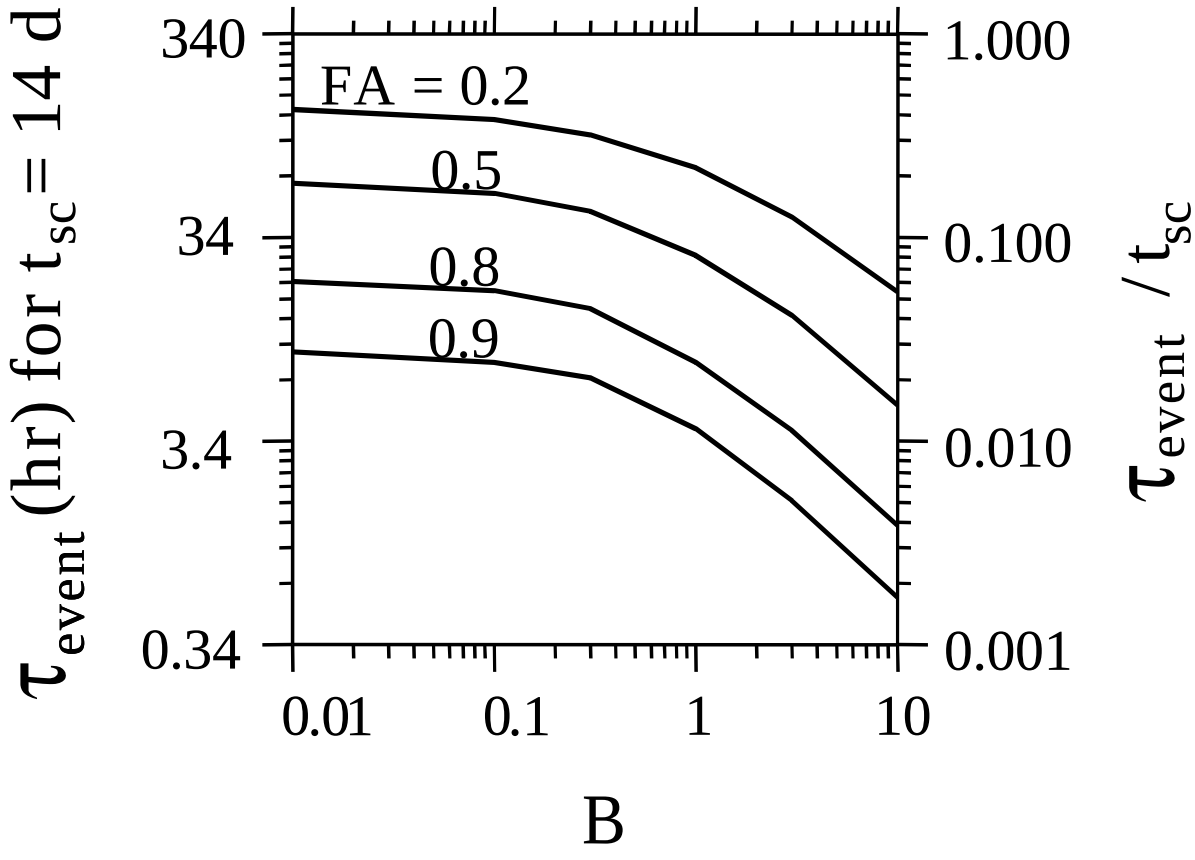
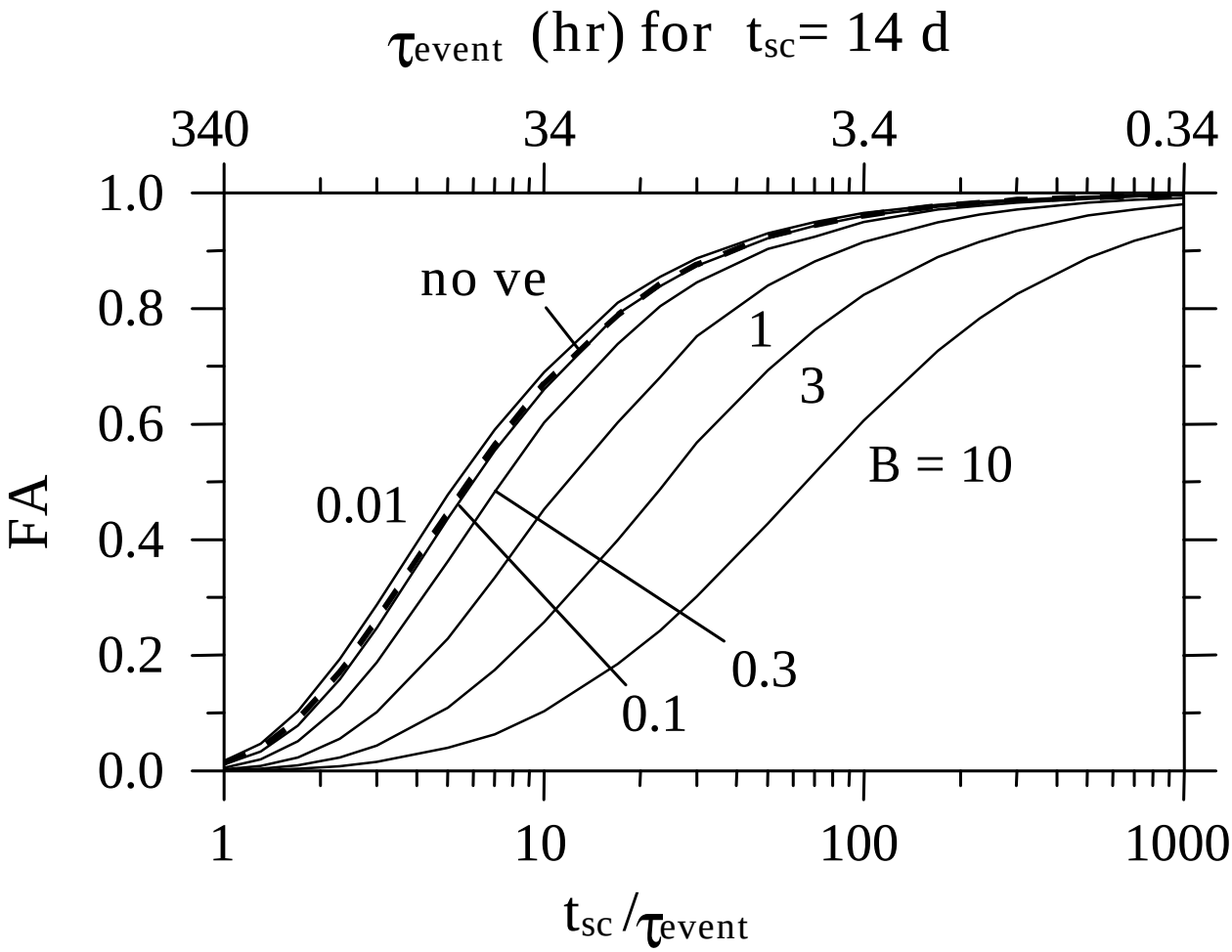


EXHIBIT A-5

EFFECT OF STRATUM CORNEUM TURNOVER ON FRACTION ABSORBED (WATER) AS A FUNCTION OF B



no ve: No viable epidermis–A model solution obtained assuming that the stratum corneum is the only barrier to dermal absorption

A.2 DERMAL ABSORPTION OF INORGANIC AND IONIZED ORGANIC COMPOUNDS

As discussed in Chapter 3, Equation 3.4 should be used in evaluating dermal absorbed dose for inorganics or highly ionized organic chemicals. As a consequence of and in keeping with recommendations in DEA (Chapter 5), using actual measured values of K_p is recommended for the inorganics. If no value is available, the permeability coefficient of 1 x 10^{-3} cm/hr is recommended as a default value (DEA) for all inorganics. Organometallics (e.g., tetraethyl lead) probably behave more like organic chemicals than inorganic chemicals and should be treated with the procedure outlined for organics.

Dermal Absorbed Dose Per Event for Inorganic Compounds – Water Contact

DA_{event} (mg/cm^2-event) is calculated for inorganics or highly ionized organic chemicals as follows:

$$DA_{event} = K_p \times C_w \times t_{event} \qquad (3.4)$$

where:

Parameter		Definition (units)	Default Value
DA_{event}	=	Absorbed dose per event (mg/cm^2-event)	–
K_p	=	Dermal permeability coefficient of compound in water (cm/hr)	Chemical-specific, see Exhibit A-6 and Appendix B
C_w	=	Chemical concentration in water (mg/cm^3)	Site-specific
t_{event}	=	Event duration (hr/event)	See Exhibit 3-2

Exhibit A-6 shows a more detailed compilation of the apparent permeability coefficients in humans for most of these inorganic chemicals at different concentrations (Hostynek et al., 1998). The data in this table may be used to give a better estimate of the apparent permeability coefficients of the corresponding inorganic chemicals when the specific species is known. This table may also be useful in evaluating high exposure concentrations that approach those in several cited experimental studies.

EXHIBIT A-6

APPARENT PERMEABILITY COEFFICIENTS OF INORGANICS

Metal	Compound	Concentration	Apparent Permeability Coefficient K_p (cm/hr)	Species and Experimental conditions
Cadmium	$CdC1_2$	0.239M	1.1×10^{-3}	guinea pig, in vivo[a]
Chromium	Na_2CrO_4	0.01-0.2 M	$1.0\text{-}2.1 \times 10^{-3}$	human, in vivo
Chromium	Na_2CrO_4	0.017-0.398 M	$0.9\text{-}1.5 \times 10^{-3}$	human, in vitro
Chromium	$CrCl_3$	0.017-0.398 M	$1.0\text{-}1.4 \times 10^{-3}$	human, in vitro
Chromium	Na_2CrO_4	0.034 M	$0.02\text{-}0.31 \times 10^{-3}$	human in vitro[b]
Chromium	$K_2Cr_2O_7$	0.03-0.25% Cr (0.006-0.081 M)	$0.01\text{-}1.0 \times 10^{-3}$	human, in vitro
Chromium	$K_2Cr_2O_7$	0.034 M Cr	0.43×10^{-3}	human, in vitro
Chromium	CrO_4	0.005 M	2.7×10^{-3}	human, in vitro[c]
Chromium	CrO_4	2.1	0.23×10^{-3}	human, in vitro[c]
Chromium	Cr(III)	0.006 M	0.4×10^{-3}	human, in vitro[c]
Chromium	Cr(III)	1.2 M	0.013×10^{-3}	human, in vitro[c]
Chromium	$CrCl_3$	0.034 M	0.041×10^{-3}	human, in vitro
Chromium	$Cr(NO_3)_3$	0.034 M	0.030×10^{-3}	human, in vitro
Mercury	$HgCl_2$	0.005 M	$0.02\text{-}0.88 \times 10^{-3}$	human, in vitro[b]
Mercury	$HgCl_2$	0.080-0.239 M	$0.10\text{-}0.93 \times 10^{-3}$	human, in vitro[b]
Mercury	Hg vapor	0.88-2.7 ng/m^3	$61.0\text{-}240.0 \times 10^{-3}$	human, in vivo
Potassium	KCl	0.155 M	2.0×10^{-3}	rabbit, in vitro[d]
Potassium	KCl	0.155 M	2.0×10^{-3}	pig, in vitro[e]
Nickel	$NiSO_4$	0.001-0.1 M	$0.003\text{-}0.01 \times 10^{-3}$	human, in vitro
Nickel	$NiSO_4$	0.001 M	$<0.002\text{-}0.27 \times 10^{-3}$	human, in vitro[f]

EXHIBIT A-6

APPARENT PERMEABILITY COEFFICIENTS OF INORGANICS (continued)

Metal	Compound	Concentration	Apparent Permeability Coefficient K_p (cm/hr)	Species and Experimental conditions
Nickel	$NiCl_2$, $NiSO_4$	1.32 mg Ni/ml	$0.003\text{-}0.23 \times 10^{-3}$	human, in vitro
Nickel	$NiCl_2$	0.62-5% $NiCl_2$	$<0.0026\text{-}0.022 \times 10^{-3}$	human, in vitro
Nickel	$NiCl_2$	5% $NiCl_2$	0.05×10^{-3}	human, in vitro
Lead	$Pb(CH_3CO_2)_2$	6 mM, 9 mmol/kg	0.0005×10^{-3}	human, in vivo
Lead	$Pb(NO_3)_2$	0.5 M	0.13×10^{-3}	human, in vitro
Sodium	NaCl	0.155 M	0.06×10^{-3}	human, in vivo
Sodium	NaCl	0.156 M	0.028×10^{-3}, fresh 0.050×10^{-3}, frozen (medians)	human, in vitro
Sodium	NaCl	0.015-1.59 M	$0.006\text{-}1.19 \times 10^{-3}$ (range)	human, in vitro

taken from Hostynek, et al., 1998

[a]In guinea pigs; there are no published data on human skin.
[b]Depends upon the time interval; larger values are for the first few hours.
[c]Through epidermis.
[d]In rabbits; there are no published data with human skin.
[e]In pigs.
[f]From various vehicles and for various durations.

Recently, Vecchia (1997) collected permeability coefficients from the literature for in vitro penetration of human skin by several ionized chemicals, including cations, anions and zwitterions. Like permeability coefficients for inorganic chemicals, these K_p values are 10^{-3} cm/hour or lower. Thus, 10^{-3} cm/hour is recommended as a conservative estimate for ionized organic chemicals.

Calculations of DAD and screening levels for inorganics using default exposure assumptions are presented in Exhibit B-4 for all inorganics with a given experimental GI Absorption value (ABS_{GI} from Exhibit 4-1).

A.3 UNCERTAINTY ANALYSIS

Sources of uncertainty in the above calculations compared with actual human exposure conditions include uncertainty in the model assumption, its formulation, and default values of the parameters used in models. Uncertainty discussion is provided below for the assumptions made in the development of the dermal absorption model, the modified Pott and Guy's K_p correlation, and the concentration of the chemicals in water.

As mentioned above, the skin is assumed to be a two-compartment model, with the two layers: stratum corneum and viable epidermis. Although exact solutions to this two-compartment model have been derived (Cleek and Bunge, 1993), these exact solutions are simplified in the recommended exposure assessment procedure for easy application for the regional risk assessors. Several assumptions are made with the application of these solutions, including the thickness of the stratum corneum ($l_{sc} = 10^{-3}$ cm) and the use of part of Equation 3.8 in Equations A.2 and A.3 to estimate D_{sc}/l_{sc}.

For the permeability coefficient, the modified Flynn database is obtained from in vitro human diffusion studies, where the K_p was estimated. Vecchia (1997), in reexamining a more comprehensive database of K_p (twice the size of the Flynn database), found one to two orders of magnitude difference in replicated measurements. The correlation coefficient ($r^2 = 0.67$) resulting from the modified Potts and Guy correlation shows that 67% of the experimentally observed variance in K_p is explained by this regression equation. The remaining 33% can be explained by inherent experimental errors and laboratory variabilities, and by the errors inherent in the choice of the K_{ow} value, whether it is measured or predicted. The residual error analysis provides the average residual error between the measured log K_p ($K_{p\text{-msd}}$) and the log K_p that is predicted ($K_{p\text{-pred}}$) using the regression. The residual error or standard error of the estimator (SEE) is calculated in Equation A.9 as:

$$SEE\ of\ \log K_p = \sqrt{\sum_{n=1}^{N} \frac{(\log K_{p-msd} - \log K_{p-pred})^2}{N-2}} \qquad (A.9)$$

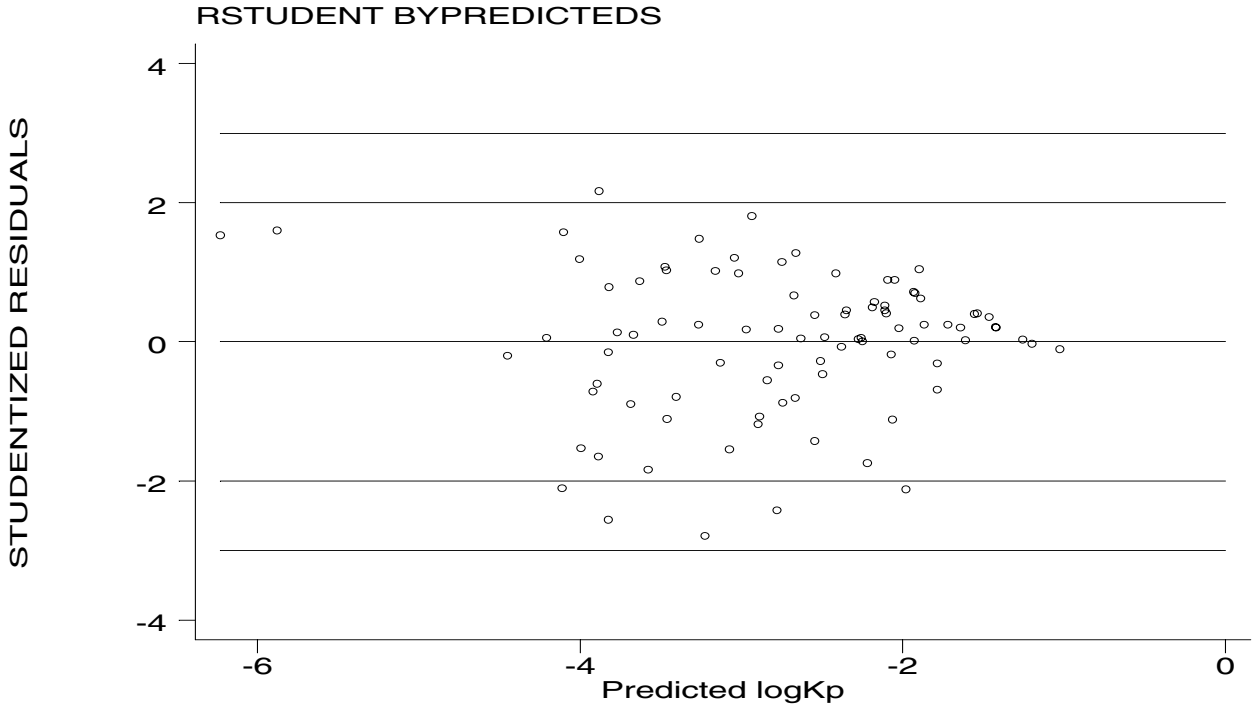
where:

Parameter		Definition (units)	Default Value
N	=	Number of chemical samples used in the estimation protocol	Site-specific
K_p	=	Dermal permeability coefficient of compound in water (cm/hr)	Chemical-specific, see Exhibit A-6 and Appendix B
$K_{p\text{-}msd}$	=	Measured K_p	Chemical-specific
$K_{p\ pred}$	=	Predicted K_p	Chemical-specific

where N is the number of chemical samples used in the estimation protocol, and $\log K_{p\text{-}msd} - \log K_{p\text{-}pred}$ is the difference between logarithms of measured ($K_{p\text{-}msd}$) and predicted values of K_p ($K_{p\text{-}pred}$). For the Potts and Guy correlation, the SEE is calculated to be 0.69. Exhibit A-7 shows that there might be a wedge pattern to the residuals, which indicates the true value could be almost anything (i.e., large scatter between predicted and experimental value) when the predicted value is small. However, when the predicted K_p is large, the value is likely to be quite close to the true value. This result is consistent with experimental uncertainties, some of which are probably not chemically dependent (e.g., penetration through appendages or damaged regions of the skin). Consequently, these sources of variability contribute less significantly when the measured value is larger.

EXHIBIT A-7

STUDENTIZED RESIDUALS OF PREDICTED K_p VALUES



The equations used for the estimation of the 95% confidence interval (lower and upper limits) are given in Equation A.10 as follows:

$$\textit{95\% upper and lower confidence level of } K_p = K_p \pm t_{(n-2-1,1-\alpha/2)} \sqrt{Var(K_p)} \qquad \text{(A.10)}$$

where:

K_p	=	Predicted K_p from Equation 3.8
Var (K_p)	=	Variance of K_p (see Draper and Smith, 1998 for definition of variance for linear regression with two independent variables)
$\sqrt{\text{Var}(K_p)}$	=	Standard error of the predicted K_p. This standard error is smaller for compounds in the Flynn data set, which results only from errors in the correlation coefficients. For new compounds, this standard error is much larger because it includes both the errors from the correlation coefficients and the residual error of the model.
t	=	Student's t distribution for two independent variables with a sample size of n and a two-sided confidence interval of 100 (1-α) = 95%

Wischut et al. (1995) provides an analysis of the reliability of five mathematical models used for simulating the permeability coefficient of substances through human skin. A database containing 123 measurements for 99 different chemicals was used in the analysis. Reliability of the models was evaluated by testing variation of regression coefficients and the residual variance for subsets of data, randomly selected from the complete database. This study found that a revised Potts and Guy model using these data had a lower residual variance than the McKone and Howd (1992) model, but that the McKone and Howd model and a revised unpublished model by Robinson (Proctor and Gamble) could provide better prediction of the permeability coefficient of highly lipophilic compounds. The Robinson model for K_p is based on a theoretical basis of a maximum permeability coefficient to account for the limiting transport properties of the epidermis. The current approach in this document, using the Potts and Guy model in combination with the parameter B in the dermal absorption model to account for the effect of permeation in the epidermis, provides the same theoretical basis as the Robinson model for K_p alone. Among all the models discussed by Wischut et al. (1995), the revised Robinson model had the lowest residual variance, which is the SEE squared.

Several other physico-chemical characteristics can also be added to improve the above correlation, e.g., molar volume (Potts and Guy, 1992). Alternatively, the data could be grouped into smaller subsets of more homogeneous chemical classes, which could yield much better correlations, as reviewed and summarized in

DEA, Table 5.6. This selection of the Potts and Guy approach is based on the universal availability of the MW and the K_{ow}, which allow for the easy extrapolation of this correlation to other organic chemicals. However, the large uncertainty resulting from these assumptions gives a 95% confidence interval of one to three orders of magnitude for the K_p estimated by this correlation, as shown in Exhibits B-1 and B-2. Because of this uncertainty, suggestions have been made to simplify the skin two-compartment diffusion model to the standard Ficks' first law, which would provide a more conservative apparent K_p. This approach is retained to balance application of more defined, available modeling to limited empirical data correlation. This approach might not improve the uncertainty much for chemicals with small lag time, reflected by using the simplified Ficks' first law equation for the inorganics. However, for those chemicals with long lag time, the two-compartment approach, together with the empirically predicted K_p, provides a much better description of the dermal absorption processes.

A note of caution is added here regarding the use of Equation 3.8 to estimate K_p for halogenated and other chemicals with large MW relative to their molar volume. Notably, the list of 200 pollutants in Appendix B includes several halogenated chemicals. Specifically, correlations like Equation 3.8 would be expected to underestimate K_p. The Flynn data set, from which Equation 3.8 was derived, consists almost entirely of hydrocarbons with a relatively constant ratio of molar volume to MW. As a consequence, for this database, there is almost no statistical difference in a regression of the K_p data, using MW to represent molecular size compared with a regression using molar volume (the quantity which is expected to control permeability) to represent molecular size. Because halogenated chemicals have a lower ratio of molar volume relative to their MW than hydrocarbons (due to the relatively weighty halogen atom), the K_p correlation based on MW of hydrocarbons will tend to underestimate permeability coefficients for halogentated organic chemicals. Unfortunately, K_p data are only available for a small number of halogenated organic chemicals [only seven in the Vecchia (1997) database, which is larger than the Flynn data set]. Vecchia (1997) found that K_p values for six of seven halogenated compounds were underestimated by a correlation of similar form to Equation 3.8. To address this problem, a new K_p correlation based on molar volume and log K_{ow} will be explored.

The EPD for the modified Potts and Guy correlation, an evaluation based on Mandel's approach, depends entirely upon the database used to generate both the correlation and the EPD. Sources of uncertainty in this Flynn database include actual chemicals used for the correlation, as well as values of K_{ow} associated with those chemicals, values which would contribute to the predictability of the correlation, as well as to the range defined by the EPD. For compounds with long lag time, where the adjustment of the fraction absorbed (FA) takes into consideration the desquamation of the skin, another uncertainty of about 10-20% arises from the assumption of steady-state and the approximation of these values from Exhibit A-5.

For highly lipophilic molecules, which are often found on Superfund sites, there are uncertainties in several steps of this approach. The permeability coefficients (K_p) of most of these compounds are outside of the predictive domain, and the large uncertainty of these values is reflected in the large range of the 95% confidence interval limit. For most of these chemicals, a value of FA < 1 is due to the effects of desquamation. However, estimation of the Dermal/Oral contribution using standard default assumptions in Exhibit B-3 for these compounds reveals that even using the lower 95% confidence limit of the K_p, a few compounds would yield a ratio Dermal/Oral > 10%, which is the criterion used for inclusion of these chemicals in the site risk assessment quantitative analysis. These results are shown in Exhibit A-8.

The recommendations from the Dermal Workgroup for these chemicals include: 1) conducting experimental studies to obtain their K_p values, for at least in vitro exposure conditions under saturation concentration, and 2) including these chemicals in the quantitative analysis and characterizing the uncertainty of the risk assessment results clearly.

For the concentrations of chemicals in water (C_w) in Equations 3.2 through 3.4, values used for C_w should reflect the available concentration of the chemicals in water for dermal absorption, and might be potentially different from the measured field values. This difference would result from the conditions of the samples and the type of chemicals to be analyzed. For the sample conditions, higher concentration of chemicals of interest might be found in unfiltered groundwater samples as compared to filtered samples, due to the existence of particulate matter and undissolved chemicals. However, to be consistent with existing RAGS guidance (U.S. EPA, 1989), it is recommended that unfiltered samples be used as the basis for estimating the chemical concentration (C_w) for calculating the dermal dose.

EXHIBIT A-8

EVALUATION OF DERMAL/ORAL CONTRIBUTION FOR LIPOPHILIC COMPOUNDS

	CHEMICAL	CAS No.	MWT	log K_{ow}	K_p 95% LCL	K_p (cm/hr) predicted	K_p 95% UCL	FA	Derm/ Oral 95% LCL K_p	Derm/ Oral average K_p	Derm/ Oral 95% UCL K_p
* 19	Benzo-a-anthracene	56553	228.3	5.66	1.7E-02	4.7E-01	1.3E+01	1	45%	1283%	36172%
* 20	Benzo-a-pyrene	50328	250.0	6.10	2.4E-02	7.0E-01	2.0E+01	1	75%	2186%	63553%
* 21	Benzo-b-fluoranthene	205992	252.3	6.12	2.4E-02	7.0E-01	2.0E+01	1	76%	2221%	64633%
* 49	Chrysene	218019	228.3	5.66	1.7E-02	4.7E-01	1.3E+01	1	45%	1283%	36172%
* 56	DDT	50293	355.0	6.36	9.2E-03	2.7E-01	7.8E+00	0.7	40%	1156%	33682%
* 62	Dibenzo(a,h)anthracene	53703	278.4	6.84	4.9E-02	1.5E+00	4.7E+01	0.6	110%	3388%	104681%
* 126	Indeno(1,2,3-CD)pyrene	193395	276.3	6.58	3.5E-02	1.0E+00	3.1E+01	0.6	77%	2307%	69550%
* 170	PCB-chlorobiphenyl, 4-	2051629	292.0	6.50	2.5E-02	7.5E-01	2.2E+01	0.6	62%	1844%	54977%
* 171	PCB-hexachlorobiphenyl	26601649	361.0	6.72	1.4E-02	4.3E-01	1.3E+01	0.5	46%	1376%	41414%
* 173	Pentachlorophenol	87865	266.4	5.86	1.4E-02	3.9E-01	1.1E+01	0.9	43%	1226%	34780%
* 176	Phenanthrene	85018	178.2	4.46	5.5E-03	1.4E-01	3.8E+00	1	11%	283%	7446%
* 186	TCDD	1746016	322.0	6.80	2.7E-02	8.1E-01	2.5E+01	0.5	66%	2003%	61044%
* 203	Tris(2,3-dibromopropyl) phosphate	126727	697.6	4.98	1.3E-05	3.9E-04	1.1E-02	1	1%	22%	642%

Note: All the above calculations are done using the same assumptions as those in Exhibit B-3

The types of chemicals in the samples would also influence the available concentration of the chemicals for dermal absorption, due to their ionization status in the samples. This discussion is detailed in Bunge and McDougal (1998). For organic chemicals in which K_p is calculated using Equation 3.8, C_w should be the concentration of only the non-ionized fraction of the chemical, C_u, to be consistent. If the organic chemical is not ionizable, C_w is equal to the total concentration of chemical in the aqueous solution, C_{tot}. For organic acids with one dominant acid-base reaction of pK_a, C_u is calculated using Equations A.11 or A.12.

For organic acids with one dominant acid-base reaction of pK_a, C_u is:

$$C_u = \frac{C_{tot}}{1 + 10^{(pH - pK_a)}} \quad \text{(A.11)}$$

For organic bases with one dominant acid-base reaction:

$$C_u = \frac{C_{tot}}{1 + 10^{(pK_a - pH)}} \quad \text{(A.12)}$$

where:

Parameter		Definition (units)	Default Value
C_u	=	Concentration of non-ionized species (mg/l)	Site-specific
C_{tot}	=	Total concentration (mg/l)	Site-specific
pK_a	=	Log of the ionization equilibrium constant of the chemical in the aqueous solution	Chemical-specific

For organic chemicals with more than one ionizable group, in general, pK_a values should be known for all ionizing reactions, and the concentration of the non-ionized species, C_u, should be calculated by combining expressions for species mass balances, electroneutrality, and reaction equilibrium.

For organic chemicals, both ionized and non-ionized species at conditions of the aqueous solution, calculate DA_{event} as the sum of the DA_{event} for the non-ionized species (using Equations 3.2 and 3.3 and the concentration of the non-ionized species, $C_w = C_u$, with the K_p of the non-ionized species) and the DA_{event} for the ionized species (using Equations 3.2 and 3.3 and the concentration of the ionized form of the chemical, $C_w = C_{tot} - C_u$, with the K_p of the ionized species). For inorganic chemicals, $C_w = C_{tot}$. If the K_p of the ionized species is always smaller than the K_p of the non-ionized species, using C_w as a default total concentration would always yield a conservative estimate of the dermal absorbed dose.

A.4 SCREENING PROCEDURE FOR CHEMICALS IN WATER

For purposes of scoping and planning an exposure and risk assessment, it is useful to know when it is important to consider dermal exposure pathways. Assessors must decide what level (from cursory to detailed) of analysis is needed to make this decision. The following screening procedure addresses this issue primarily by

analyzing when the dermal exposure route is likely to be significant when compared to the other routes of exposure. This discussion is based on methodology presented in Chapter 9 of the DEA using the parameters provided in this current guidance, and provides the basis for the current Chapter 2 on Hazard Identification. Readers are encouraged to consult the DEA document for more details.

The first step is to identify the chemicals of interest. The next step is to make a preliminary analysis of the chemical's environmental fate and the population behavior to judge whether dermal contact may occur. The third step is to review the dermal toxicity of the compound and determine if it can cause acute effects. The scope of this screening procedure has been limited to dermal exposure assessments in support of risk assessments for systemic chronic health effects. However, consideration of other types of health effects can be a critical factor in determining the overall importance of the dermal exposure route. Even if the amount of a compound contacting the skin is small compared to the amount ingested or inhaled, the dermal route can still be very important to consider for compounds that are acutely toxic to the skin.

The remainder of this procedure evaluates the importance of dermal contact by comparing it to other exposure routes that are likely to occur concurrently. For example, the importance of dermal contact with water is evaluated by assuming that the same water is used for drinking purposes as for swimming or bathing and comparing these two pathways. However, the underlying assumption that concurrent exposure routes will occur is not valid in all situations. For example, the water in a contaminated quarry may not be used as a domestic water supply but may be used for occasional recreational swimming. Even where concurrent exposure routes occur, the contaminant concentrations may differ. For example, in a situation involving a contaminated river used as a domestic water supply, swimmers may be exposed to a higher concentration in the river than occurs during ingestion of tap water due to treatment. Thus, the assessor should confirm the assumptions that concurrent exposures occur and that the same contaminant levels apply. Where these assumptions are not valid, dermal exposure should be evaluated independently.

Where the same water supply is used for drinking and bathing, the importance of dermal contact with water can be evaluated by comparing the possible absorbed dose occurring during bathing relative to that occurring as a result of ingestion, represented by the standard default of drinking 2 liters of water per day per person. Assuming a 35 min (0.58 hr) showering (RME value from Exhibit 3-2), for all the 200 pollutants included in Exhibit B-3, the following ratio of the dermal absorbed dose relative to ingestion is presented in Equations A.13 to A.16 for organics and Equation A.13 for inorganics.

$$\frac{Dermal\ Dose}{Ingestion\ Dose} = \frac{DA_{event}(SA)(EV)}{(C_w)(IR)(1000cm^3/L)(ABS_{GI})} \quad (A.13)$$

For short exposure ($t_{event} < t^*$):

where:

$$\frac{Dermal\ Dose}{Ingestion\ Dose} = \frac{2(C_w)(FA)(K_P)(SA)(EV)\sqrt{\frac{6\ (\tau_{event} \times t_{event})}{\pi}}}{(C_w)(IR)(1000cm^3/L)(ABS_{GI})} \quad (A.14)$$

Parameter		Definition (units)	Default value
DA_{event}	=	Absorbed dose per event (mg/cm^2-event)	Equation 3.2
C_w	=	Chemical concentration in water (mg/cm^3)	1 mg/l or 1 ppm
FA	=	Fraction absorbed (dimensionless)	Exhibit A-5
K_p	=	Dermal permeability coefficient of compound in water (cm/hour)	Equation 3.8
τ_{event}	=	Lag time per event (hr/event)	Equation A.4
t_{event}	=	Event duration (hr/event)	35 minutes
SA	=	Skin surface area available for contact (cm^2)	18,000 cm^2
EV	=	Event frequency (events/day)	1 event/day
IR	=	Water ingestion rate (L/day)	2 L/day
ABS_{GI}	=	Fraction of contaminant absorbed in the gastrointestional tract (dimensionless)	1
t*	=	Time to reach steady-state (hr)	Chemical-specific

Assuming an adult ingestion rate (IR) of 2 L/day, GI tract absorption fraction (ABS_{GI}) of 1, a skin area of 18,000 cm^2, and several other factors (Equation A.13 and A.14), this ratio becomes:

$$\frac{Dermal\ Dose}{Ingested\ Dose} = 19\ FA\ K_p\sqrt{\tau_{event}} \qquad (A.15)$$

where:

Parameter		Definition (units)	Default Value
K_p	=	Dermal permeability coefficient of compound in water (cm/hour)	Chemical-specific, see Appendix B
τ_{event}	=	Lag time per event (hr/event)	Chemical-specific, see Appendix B
FA	=	Fraction absorbed (dimensionless)	Chemical-specific, see Appendix B

Using the screening criteria of 10% dermal to ingestion, the dermal dose exceeds 10% of the ingested dose as presented in Equation A.15 when:

$$For\ organics: \frac{Dermal}{Ingestion} > 10\%\ when\ (FA)\ (K_p)\ \sqrt{\tau_{event}} > 0.005 \qquad (A.16)$$

It should be noted that this screening procedure for exposure to water-borne chemicals is limited to the ingestion and showering pathways (using RME value for showering duration) for adults, and does not include consideration of swimming exposures, and therefore should not be used for screening chemicals in surface water where exposure may be through swimming activity. This procedure has also been evaluated to be more conservative than the scenario of children bathing for one hour (RME value for children bathing). In addition, site-specific scenarios and exposure conditions should always be used when available.

The screening criterion of 10% dermal exposure to ingestion exposure was selected to ensure that this screening procedure does not eliminate compounds of potential concern. This criterion introduces a safety factor of 10. For compounds with low GI absorption (e.g., < 50%), this screening procedure should not be used, and the actual GI absorption fraction should be used to adjust for the toxicity effect (see Section 3.2 on Dermal Absorption from Soil for methodology).

Exhibit B-3 in Appendix B lists more than 200 common organic pollutants and their permeability coefficients. The compounds are listed in alphabetical order. Assessors can check this list to see if the compound of interest is on the list. Chemicals which are considered appropriate to evaluate for the dermal pathway are indicated in Exhibit B-3 with a "Y" in the "Chemicals To Be Assessed" column. Exhibit B-4 provides the same information for all inorganics with a GI absorption fraction provided in Exhibit 4-1.

For inorganics, using the same procedure, the screening equation results in Equation A.17. ABS_{GI} should be expressed as a percent in Equation A.17.

$$\textit{For inorganics}: \quad \frac{Dermal}{Ingestion} > 10\% \ when \ K_p > 1.9 \ x \ 10^{-4} \ ABS_{Gi} \qquad (A.17)$$

A.5 PROCEDURES FOR CALCULATING DERMAL DOSE

This section presents the steps required to identify appropriate values for the exposure and absorption parameters, and notes how to combine these values to estimate the dermally absorbed dose of a compound in an aqueous medium.

Step 1: Select Values for Exposure Parameters

Site-specific measurement or modeling is required to identify values for the concentration of the contaminant(s) of interest in water. Concentration values should be used that are representative of the location and time period where exposure occurs. Lacking site-specific data to the contrary, the default values presented in Exhibit A-9 are recommended for the parameters characterizing water contact during bathing.

Background information and the rationales supporting default recommendations are obtained from the Exposure Factors Handbook (U.S. EPA, 1997a), and are briefly summarized here. The exposed skin area is based on the assumption that people are entirely immersed during bathing or swimming; the corresponding body areas were presented in the Exposure Factors Handbook. The bathing frequency of 350 days/year is based on information that most people bathe once per day (1 event/day). The bathing event time is based on the range given in the Exposure Factors Handbook to be representative of baths as well as showers and considering that

some water residue remains on the skin for a brief period after bathing. The exposure duration of 9 to 30 years represents the likely time that a person spends in one residence, with 9 years used for central tendency residential exposure duration, and 30 years used for high end residential exposure duration.

EXHIBIT A-9

DEFAULT VALUES FOR WATER CONTACT EXPOSURE PARAMETERS

Parameter	Bathing Default Parameters
Adult Skin Area (cm^2)	18,000
Event Time and Frequency	35 min/event, 1 event/day and 350 days/yr
Exposure Duration (years)	9 - 30

Step 2: Select Normalizing Parameters Used in Dose Equations

Dose estimates are normalized over body weight and time to express them in a manner that is consistent with dose-response relationships. An average body weight [70 kg for adults, see U.S. EPA, 1989 for age-specific values for children] is used for this purpose. For cancer risk assessments, an averaging time equal to a mean lifetime (70 yr) is used. For noncancer risk assessments, an averaging time equal to the exposure duration is used. (For more details regarding these parameters, see U.S. EPA, 1989.)

Step 3: Estimate DA_{event}

These equations were given in Chapter 3 and Appendix A. Section A.1 gives the equations for the organics; Section A.2 gives the equations and values for inorganics. For organics:

Dermal Absorbed Dose per event for Organic Compounds - Water Contact

DA_{event} (mg/cm^2-event) is calculated for oganic compounds as follows :

$$If\ t_{event} \le t^*,\ then:\ DA_{event} = 2\ FA \times K_p \times C_w \sqrt{\frac{6\ \tau_{event} \times t_{event}}{\pi}} \tag{3.2}$$

$$If\ t_{event} > t^*,\ then:\ DA_{event} = FA \times K_p \times C_w \left[\frac{t_{event}}{1 + B} + 2\ \tau_{event}\left(\frac{1 + 3\ B + 3\ B^2}{(1 + B)^2}\right)\right] \tag{3.3}$$

where:

Parameter		Definition (units)	Default Value
DA_{event}	=	Absorbed dose per event (mg/cm^2-event)	–
FA	=	Fraction absorbed (dimensionless)	Chemical-specific, See Appendix B
K_p	=	Dermal permeability coefficient of compound in water (cm/hr)	Chemical-specific, See Appendix B
C_w	=	Chemical concentration in water (mg/cm^3)	Site-specific
τ_{event}	=	Lag time per event (hr/event)	Chemical-specific, See Appendix B
t_{event}	=	Event duration (hr/event)	See Exhibit 3-2
t^*	=	Time to reach steady-state (hr) = 2.4 τ_{event}	Chemical-specific, See Eq. A.5 to A.8
B	=	Dimensionless ratio of the permeability coefficient of a compound through the stratum corneum relative to its permeability coefficient across the viable epidermis (ve) (dimensionless).	Chemical-specific, See Eq. A.1

Equations A.1 to A.8 update those in the DEA for estimating all parameters needed to evaluate DA_{event}:

$$B = \frac{K_p}{K_{p,ve}} \simeq K_p \frac{\sqrt{MW}}{2.6} \quad (as\ an\ approximation) \tag{A.1}$$

where:

Parameter		Definition (units)	Default Value
B	=	Dimensionless ratio of the permeability coefficient of a compound through the stratum corneum relative to its permeability coefficient across the viable epidermis (ve)	–
$K_{p,ve}$	=	Steady-state permeability coefficient through the viable epidermis (ve) (cm/hr)	$K_{p,ve} = K_{ew}D_e/L_e$, K_{ew} =1 assuming EPI behaves essentially as water; $L_e = 10^{-2}$ cm, $D_e = 7.1 \times 10^{-6}$/MW cm^2/s assuming $D_e = 10^{-6}$ cm^2/s when MW = 50 (Bunge and Cleek, 1995)
K_p	=	Dermal permeability coefficient in water (cm/hr)	Equation 3.8
MW	=	Molecular weight (g/mole)	Chemical-specific

Using the same approach as in DEA, Equation 5.13, A.2 and A.3 estimate D_{sc}/l_{sc} (cm/hr).

$$\log \frac{D_{sc}}{l_{sc}} = -2.80 - 0.0056\ MW \tag{A.2}$$

or:

$$\frac{D_{sc}}{l_{sc}} = 10^{(-2.80\ -\ 0.0056\ MW)} \tag{A.3}$$

where:

Parameter		Definition (units)	Default Value
D_{sc}	=	Effective diffusion coefficient for chemical transfer through the stratum corneum (cm^2/hr)	Chemical-specific
l_{sc}	=	Apparent thickness of stratum corneum (cm)	10^{-3}
MW	=	Molecular weight (g/mole)	Chemical-specific

Assuming $l_{sc} = 10^{-3}$ cm as a default value, t_{event} can be evaluated using Equation A.4:

$$\tau_{event} = \frac{l_{sc}^2}{6\ D_{sc}} = 0.105 \times 10^{(0.0056\ MW)} \qquad \text{(A.4)}$$

where:

Parameter		Definition (units)	Default Value
τ_{event}	=	Lag time per event (hr/event)	Chemical-specific
D_{sc}	=	Effective diffusion coefficient for chemical transfer through the stratum corneum (cm^2/hr)	Chemical-specific
l_{sc}	=	Apparent thickness of stratum corneum (cm)	10^{-3}
MW	=	Molecular weight (g/mole)	Chemical-specific

Calculate t^*:

$$If\ B \leq 0.6,\ then\ t^* = 2.4\ \tau_{event} \tag{A.5}$$

$$If\ B > 0.6,\ then\ t^* = (b - \sqrt{b^2 - c^2})\ \frac{l_{sc}^2}{D_{sc}} \tag{A.6}$$

where:

$$b = \frac{2\ (1 + B)^2}{\pi} - c \tag{A.7}$$

$$c = \frac{1 + 3B + 3B^2}{3(1 + B)} \tag{A.8}$$

where:

Parameter		Definition (units)	Default Value
B	=	Dimensionless ratio of the permeability coefficient of a compound through the stratum corneum relative to its permeability coefficient across the viable epidermis (ve) (dimensionless).	Chemical-specific
t^*	=	Time to reach steady-state (hr)	Chemical-specific
τ_{event}	=	Lag time per event (hr/event)	Chemical-specific
D_{sc}	=	Effective diffusion coefficient for chemical transfer through the stratum corneum (cm^2/hr)	Chemical-specific
l_{sc}	=	Apparent thickness of stratum corneum (cm)	10^{-3}
b, c	=	Correlation coefficients which have been fitted to the Flynn's data to give Equation 3.8	Chemical-specific

For Inorganics:

DA_{event} (mg/cm^2-event) is calculated for inorganics or highly ionized organic chemicals as follows:

Dermal Absorbed Dose Per Event for Inorganic Compounds – Water Contact

$$DA_{event} = K_p \times C_w \times t_{event} \tag{3.4}$$

where:

Parameter		Definition (units)	Default Value
DA_{event}	=	Absorbed dose per event (mg/cm^2-event)	–
K_p	=	Dermal permeability coefficient of compound in water (cm/hr)	Chemical-specific, see Exhibit A-6 and Appendix B
C_w	=	Chemical concentration in water (mg/cm^3)	Site-specific, non ionized fraction, see Appendix A for more discussion
t_{event}	=	Event duration (hr/event)	See Exhibit 3-2

Step 4: Integrate Information to Determine Dermal Dose

Finally, the dermal dose is calculated by collecting the information from the earlier steps and substituting into Equation 3.1.

Dermal Absorbed Dose – Water Contact

$$DAD = \frac{DA_{event} \times EV \times ED \times EF \times SA}{BW \times AT} \quad (3.1)$$

where:

Parameter		Definition (units)	Default Value
DAD	=	Dermally Absorbed Dose (mg/kg-day)	–
DA_{event}	=	Absorbed dose per event (mg/cm^2-event)	Chemical-specific, see Eq. 3.2 and 3.3
SA	=	Skin surface area available for contact (cm^2)	See Exhibit 3-2
EV	=	Event frequency (events/day)	See Exhibit 3-2
EF	=	Exposure frequency (days/year)	See Exhibit 3-2
ED	=	Exposure duration (years)	See Exhibit 3-2
BW	=	Body weight (kg)	70 kg
AT	=	Averaging time (days)	noncarcinogenic effects AT = ED x 365 d/yr carcinogenic effects AT = 70 yr x 365 d/yr

Step 5: Further Refinement of Dose Estimate

Where dose estimates are desired for children during specific age ranges, a summation approach is needed to reflect changes in skin surface area and body weight. Assuming all other exposure factors remain constant over time, Equation 3.1 is modified to Equation A.18; where m and n represent the age range of interest. The skin surface areas for the ages of interest can be obtained from Exhibit C-3 (Appendix C) and body weights from the Exposure Factors Handbook (U.S. EPA, 1997a).

Dermal Absorbed Dose - Water Contact
Surface Area/Body Weight Adjustment

$$DAD = \frac{DA_{event}\ EV\ EF}{AT} \sum_{i=m}^{n} \frac{SA_i\ ED_i}{BW_i} \qquad \text{(A.18)}$$

where:

Parameter		Definition (units)	Default Value
DAD	=	Dermal Absorbed Dose (mg/kg-day)	–
Da_{event}	=	Absorbed dose per event (mg/cm^2-event)	Chemical-specific, see Equation 3.12
SA	=	Skin surface area available for contact (cm^2)	See Appendix C and Equations 3.13-3.16
EV	=	Event frequency (events/day)	See Exhibit 3-5
EF	=	Exposure frequency (days/year)	See Exhibit 3-5
ED	=	Exposure duration (years)	See Exhibit 3-5
BW	=	Body weight (kg)	EFH (U.S. EPA, 1997a)
AT	=	Averaging time (days)	noncarcinogenic effects AT = ED x 365 d/yr carcinogenic effects AT = 70 yr x 365 d/yr

Step 6: Screening

$$\frac{Dermal\ Dose}{Ingestion\ Dose} = \frac{DA_{event}(SA)(EV)}{(C_w)(IR)(1000cm^3/L)(ABS_{GI})} \qquad \text{(A.13)}$$

where:

Parameter		Definition (units)	Default Value
DA_{event}	=	Absorbed dose per event (mg/cm^2-event)	Chemical-specific, see Equation 3.12
C_w	=	Chemical concentration in water (mg/cm^3)	Site-specific, non ionized fraction, see Appendix A for more discussion
SA	=	Skin surface area available for contact (cm^2)	See Appendix C and Equations 3.13-3.16
EV	=	Event frequency (events/day)	See Exhibit 3-5
IR	=	Water ingestion rate (L/day)	
ABS_{GI}	=	Fraction of contaminant absorbed in the gastrointestional tract (dimensionless) - For Organics: ABS_{GI} is assumed to be 1 (or 100% absorption) - For Inorganics: ABS_{GI} is chemical specific, given by Exhibit 4-1	

Step 7: Evaluate Uncertainty

As explained in Chapter 4 and Section A.4, the procedures for estimating the dermal dose from water contact are very new and should be approached with caution. One "reality check" that assessors should make for bathing scenarios is to compare the total amount of contaminant in the bathing water to the dose. The amount of contaminant in the water is easily computed by multiplying the contaminant concentration by the volume of water used (showers typically use 5 to 15 gal/min). Obviously, the dose cannot exceed the amount of contaminant in the water. In fact, it seems unlikely that a high percentage of the contaminant in the water could be dermally absorbed. As a preliminary guide, if the dermal dose estimate exceeds 50% of the contaminant in the water, the assessor should reexamine the assumptions and sources of data. Volatile compounds have been shown to volatilize significantly during showering. Andelman (1988) found that about 90% of TCE volatilized during showering. This would suggest that the effective concentration of volatile contaminants in water, and thus the resulting dermal dose for volatiles, may be reduced. So for volatile compounds, assessors may want to assume a reduced contaminant concentration in water contacting the skin as part of a sensitivity analysis.

The dermal permeability estimates are probably the most uncertain of the parameters in the dermal dose equation. As discussed in Section A.4, the measured values probably have an uncertainty of plus or minus a half order of magnitude. In addition, FA is obtained graphically to the nearest one significant figure, and therefore contributes somewhat to the uncertainty of the final calculation. Accordingly, the final dose and risk estimates should be considered highly uncertain. Some idea of the range of possible values can be obtained by first using average or typical values for each parameter to get a typical dose estimate. Setting two or three of the most variable parameters to their upper values and the others to their average values will also yield some idea of the possible upper-dose estimate.

A.5.1 STEPWISE PROCEDURE FOR CALCULATING DERMAL DOSE USING SPREADSHEETS

Revised spreadsheets have been set up on Microsoft Excel to support the calculations for the dermally absorbed dose described in Chapter 3 and this Appendix for the organics (ORG04_01.XLS) and the inorganics (INORG04_01.XLS). These spreadsheets replace the previous LOTUS 123 files sent to the Regions with the 1992 document. Electronic versions of the spreadsheets are provided on the Internet (http://www.epa.gov/superfund/programs/risk/ragse/index.htm). The spreadsheets provide data for 209 organics and 19 inorganic chemicals, with all equations included. Calculations are also given for these chemicals, using either default or assumed values for the purpose of illustration.

Results from the spreadsheets for the organics are tabulated in Appendix B, Exhibits B-1 to B-3. For the organics, Equations A.1 to A.8 and 3.1 to 3.8 are set up for over 200 compounds in the spreadsheet. Given the log K_{ow} and MW of chemicals, Kp is estimated using Equation 3.8. Depending on the exposure duration (t_{event}), either Equation 3.2 or 3.3 should be selected to be used in Equation 3.1. All other default exposure factors in Equation 3.1 are obtained from Chapter 3 and Appendix A.

Compounds from Exhibits B-2 and B-3 marked with an * are the highly lipophilic compounds which are listed in Exhibit A-2. Compounds from the organics list marked with an ** are the halogenated compounds.

For each new site risk assessment, the following procedures need to be followed:

Step 1: Input parameter values common to all chemicals at the top of the spreadsheet, i.e. SA, t_{event}, EV, EF, ED, BW, AT. Default values for all these parameters can be found in Chapter 3 and in Appendix A.

Step 2: Compile the list of chemicals on the site and their concentrations.

Step 3: Find the chemicals on the spreadsheet provided. If not listed, find their Molecular Weight and Log K_{ow} and enter data for the new chemicals at the bottom of the spreadsheet. Copy the respective formulas for all the calculations to these new chemicals. Numerical values corresponding to the conditions on the site will be calculated automatically. Delete the ones not found on the site to obtain your own spreadsheet for the site.

Step 4: Enter the actual concentration of each chemical found on the site in the column marked "Conc".

Step 5: Check in the Column "Chemicals to be assessed" to find out whether or not you need to include that chemical in your Risk Assessment.

Step 6: Check on all Print setup for your particular printer. You can rearrange the columns to print only the values of interest by copying your spreadsheet to a new spreadsheet, pasting the values only, and not the formulas. This new spreadsheet can be formatted freely, as well as imported into a wordprocessing software as tables. Note that any changes in calculations still need to be done in the original spreadsheet with the embedded equations.

APPENDIX B

SCREENING TABLES AND REFERENCE VALUES FOR THE WATER PATHWAY

Note:

The following exhibits are provided using K_{ow} values from the DEA (U.S. EPA, 1992a). EPA is currently revising criteria for selecting K_{ow} values, and these exhibits will be updated with appropriate K_{ow} values, as well as expanded to include more chemicals. The new changes may also affect Equation 3.8 and all other related evaluations.

EXHIBIT B-1

FLYNN DATA SET

Notes:

The predicted K_p was calculated using Equation 3.8 and the Lotus spreadsheet software, and is the average value of the regression correlation equation.

95% LCL (lower confidence level) and UCL (upper confidence level) of K_p are calculated using the statistical software package STATA (STATA Corporation, 702 University Drive East, College Station, Texas 77840, USA).

Compounds in italics are common to both the Flynn data set and the organic data set. For these compounds, the 95% LCL and UCL are obtained from Exhibit B-1 and are common to both Exhibits B-1 and B-2.

	Flynn's in vitro experimental data	**MW**	**Log K_{ow}**	**K_p 95% LCL**	**K_p Predicted (cm/hr)**	**K_p Measured (in vitro data) cm/hr**	**K_p 95% UCL**
1	Aldosterone	360.4	1.08	4.4E-05	7.8E-05	3.0E-06	1.4E-04
2	Amobarbital	226.3	1.96	1.2E-03	1.7E-03	2.3E-03	2.4E-03
3	Atropine	289.4	1.81	4.1E-04	5.9E-04	8.5E-06	8.6E-04
4	Barbital	184.2	0.65	2.4E-04	3.9E-04	1.1E-04	6.4E-04
5	Benzyl alcohol	108.1	1.10	1.3E-03	2.1E-03	6.0E-03	3.4E-03
6	*4-Bromophenol*	*173*	*2.59*	*5.8E-03*	*8.8E-03*	*3.6E-02*	*1.3E-02*
7	*2,3-Butanediol*	*90.12*	*-0.92*	*5.2E-05*	*1.2E-04*	*4.0E-05*	*2.8E-04*
8	Butanoic acid (butyric acid)	88.1	0.79	9.9E-04	1.7E-03	1.0E-03	2.9E-03
9	*n-Butanol*	*74.12*	*0.88*	*1.3E-03*	*2.3E-03*	*2.5E-03*	*4.0E-03*
10	2-Butanone	72.1	0.28	5.1E-04	9.5E-04	4.5E-03	1.8E-03
11	Butobarbital	212.2	1.65	8.8E-04	1.3E-03	1.9E-04	1.8E-03
12	*4-Chlorocresol*	*142.6*	*3.10*	*1.7E-02*	*2.9E-02*	*5.5E-02*	*4.9E-02*
13	*2-Chlorophenol*	*128.6*	*2.15*	*5.2E-03*	*8.0E-03*	*3.3E-02*	*1.2E-02*
14	*4-Chlorophenol*	*128.6*	*2.39*	*7.3E-03*	*1.2E-02*	*3.6E-02*	*1.8E-02*
15	Chloroxylenol	156.6	3.39	2.1E-02	3.7E-02	5.2E-02	6.6E-02
16	Codeine	299.3	0.89	7.6E-05	1.3E-04	4.9E-05	2.2E-04
17	Cortexolone (11-desoxy-17-hydroxycorticosterone)	346.4	2.52	5.6E-04	8.4E-04	7.4E-05	1.3E-03
18	Cortexone (deoxycorticosterone)	330.4	2.88	1.2E-03	1.8E-03	4.5E-04	2.7E-03
19	Corticosterone	346.4	1.94	2.2E-04	3.5E-04	6.0E-05	5.4E-04
20	Cortisone	360.5	1.42	7.7E-05	1.3E-04	1.0E-05	2.2E-04
21	*o-Cresol*	*108.1*	*1.95*	*4.8E-03*	*7.7E-03*	*1.6E-02*	*1.2E-02*
22	*m-Cresol*	*108.1*	*1.96*	*4.9E-03*	*7.8E-03*	*1.5E-02*	*1.2E-02*
23	*p-Cresol*	*108.1*	*1.95*	*4.8E-03*	*7.7E-03*	*1.8E-02*	*1.2E-02*
24	*n-Decanol*	*158.3*	*4.57*	*9.5E-02*	*2.2E-01*	*7.9E-02*	*5.1E-01*

EXHIBIT B-1

FLYNN DATA SET (continued)

	Flynn's in vitro experimental data	MW	Log K_{ow}	K_p 95% LCL	K_p Predicted (cm/hr)	K_p Measured (in vitro data) cm/hr	K_p 95% UCL
25	*2,4-Dichlorophenol*	*163*	*3.06*	*1.2E-02*	*2.1E-02*	*6.0E-02*	*3.4E-02*
26	Digitoxin	764.9	1.86	3.5E-07	1.4E-06	1.3E-05	5.4E-06
27	Ephedrine	165.2	1.03	5.8E-04	9.0E-04	6.0E-03	1.4E-03
28	B-estradiol	272.4	2.69	2.0E-03	2.8E-03	3.0E-04	4.1E-03
29	B-estradiol (2)	272.4	2.69	2.0E-03	2.8E-03	5.2E-03	4.1E-03
30	Estriol	288.4	2.47	1.2E-03	1.7E-03	4.0E-05	2.4E-03
31	Estrone	270.4	2.76	2.2E-03	3.3E-03	3.6E-03	4.7E-03
32	*Ethanol*	*46.07*	*-0.31*	*2.6E-04*	*5.4E-04*	*7.9E-04*	*1.1E-03*
33	*2-Ethoxy ethanol (Cellosolve)*	*90.12*	*-0.32*	*1.5E-04*	*3.0E-04*	*2.5E-04*	*6.1E-04*
34	*Ethyl ether*	*74.12*	*0.89*	*1.4E-03*	*2.3E-03*	*1.6E-02*	*4.0E-03*
35	*4-Ethylphenol*	*122.2*	*2.58*	*1.0E-02*	*1.7E-02*	*3.5E-02*	*2.7E-02*
36	Etorphine	411.5	1.86	7.6E-05	1.3E-04	3.6E-03	2.3E-04
37	Fentanyl	336.5	4.37	8.4E-03	1.6E-02	5.6E-03	3.2E-02
38	Fentanyl (2)	336.5	4.37	8.4E-03	1.6E-02	1.0E-02	3.2E-02
39	Fluocinonide	494.6	3.19	1.8E-04	3.5E-04	1.7E-03	6.8E-04
40	Heptanoic acid (enanthic acid)	130.2	2.50	8.4E-03	1.3E-02	2.0E-02	2.1E-02
41	*n-Heptanol*	*116.2*	*2.62*	*1.2E-02*	*1.9E-02*	*3.2E-02*	*3.2E-02*
42	Hexanoic acid (caproic acid)	116.2	1.90	4.1E-03	6.4E-03	1.4E-02	1.0E-02
43	*n-Hexanol*	*102.2*	*2.03*	*5.8E-03*	*9.3E-03*	*1.3E-02*	*1.5E-02*
44	Hydrocortisone	362.5	1.53	9.0E-05	1.5E-04	3.0E-06	2.5E-04
45	Hydrocortisone (2)	362.5	1.53	9.0E-05	1.5E-04	1.2E-04	2.5E-04
46	[Hydrocortisone-21-yl]-N,N dimethyl succinamate	489.6	2.03	3.1E-05	6.3E-05	6.8E-05	1.3E-04
47	[Hydrocortisone-21-yl]-hemipimelate	504.6	3.26	1.7E-04	3.4E-04	1.8E-03	6.8E-04
48	[Hydrocortisone-21-hemisuccinate	462.5	2.11	5.3E-05	1.0E-04	6.3E-04	1.9E-04
49	[Hydrocortisone-21-yl]-hexanoate	460.6	4.48	1.8E-03	3.9E-03	1.8E-02	8.2E-03
50	[Hydrocortisone-21-yl]-6-hydroxy hexanoate	476.6	2.79	1.3E-04	2.4E-04	9.1E-04	4.5E-04
51	[Hydrocortisone-21-yl]-octanoate	488.7	5.49	4.8E-03	1.3E-02	6.2E-02	3.3E-02
52	[Hydrocortisone-21-yl]-pimelamate	503.6	2.31	3.9E-05	8.0E-05	8.9E-04	1.6E-04
53	[Hydrocortisone-21-yl]-proprionate	418.5	3.00	4.1E-04	6.9E-04	3.4E-03	1.2E-03
54	[Hydrocortisone-21-yl]-succinamate	461.6	1.43	1.8E-05	3.6E-05	2.6E-05	7.3E-05
55	Hydromorphone	285.3	1.25	1.7E-04	2.7E-04	1.5E-05	4.1E-04
56	Hydroxypregnenolone	330.4	3.00	1.4E-03	2.2E-03	6.0E-04	3.3E-03
57	17a-Hydroxyprogesterone	330.4	2.74	9.7E-04	1.5E-03	6.0E-04	2.2E-03
58	Isoquinoline	129.2	2.03	4.3E-03	6.6E-03	1.7E-02	1.0E-02
59	Meperidine	247	2.72	2.8E-03	4.1E-03	3.7E-03	6.0E-03
60	*Methanol*	*32.04*	*-0.77*	*1.4E-04*	*3.2E-04*	*5.0E-04*	*7.3E-04*

EXHIBIT B-1

FLYNN DATA SET (continued)

	Flynn's in vitro experimental data	MW	Log K_{ow}	K_p 95% LCL	K_p Predicted (cm/hr)	K_p Measured (in vitro data) cm/hr	K_p 95% UCL
61	Methyl-[hydrocortisone-21-yl]-succinate	476.6	2.58	9.1E-05	1.7E-04	2.1E-04	3.3E-04
62	Methyl-[hydrocortisone-21-yl]-pimelate	518.6	3.70	2.6E-04	5.5E-04	5.4E-03	1.2E-03
63	*Methyl-4-hydroxy benzoate*	*152.1*	*1.96*	*3.0E-03*	*4.4E-03*	*9.1E-03*	*6.5E-03*
64	Morphine	285.3	0.62	5.8E-05	1.0E-04	9.3E-06	1.8E-04
65	*2-Naphthol*	*144.2*	*2.84*	*1.1E-02*	*1.9E-02*	*2.8E-02*	*3.1E-02*
66	Naproxen	230.3	3.18	6.6E-03	1.0E-02	4.0E-04	1.6E-02
67	Nicotine	162.2	1.17	7.6E-04	1.2E-03	1.9E-02	1.8E-03
68	Nitroglycerine	227.1	2.00	1.3E-03	1.8E-03	1.1E-02	2.5E-03
69	*3-Nitrophenol*	*139.1*	*2.00*	*3.7E-03*	*5.5E-03*	*5.6E-03*	*8.4E-03*
70	*4-Nitrophenol*	*139.1*	*1.91*	*3.2E-03*	*4.8E-03*	*5.6E-03*	*7.3E-03*
71	*n-Nonanol*	*144.3*	*3.77*	*4.0E-02*	*7.8E-02*	*6.0E-02*	*1.5E-01*
72	Octanoic acid (caprylic acid)	144.2	3.00	1.4E-02	2.4E-02	2.5E-02	4.0E-02
73	*n-Octanol*	*130.2*	*2.97*	*1.6E-02*	*2.7E-02*	*5.2E-02*	*4.7E-02*
74	Pentanoic acid (valeric acid)	102.1	1.30	1.9E-03	3.1E-03	2.0E-03	4.9E-03
75	*n-Pentanol*	*88.15*	*1.56*	*3.4E-03*	*5.5E-03*	*6.0E-03*	*8.9E-03*
76	Phenobarbital	232.2	1.47	5.1E-04	7.4E-04	4.6E-04	1.1E-03
77	*Phenol*	*94.11*	*1.46*	*2.7E-03*	*4.3E-03*	*8.1E-03*	*7.0E-03*
78	Pregnenolone	316.5	3.13	2.0E-03	3.2E-03	1.5E-03	4.9E-03
79	Progesterone	314.4	3.77	5.0E-03	8.6E-03	1.5E-03	1.5E-02
80	*n-Propanol*	*60.1*	*0.25*	*5.6E-04*	*1.1E-03*	*1.4E-03*	*2.0E-03*
81	*Resorcinol*	*110.1*	*0.80*	*7.7E-04*	*1.3E-03*	*2.4E-04*	*2.1E-03*
82	Salcylic acid	138.1	2.26	5.4E-03	8.4E-03	6.3E-03	1.3E-02
83	Scopolamine	303.4	1.24	1.3E-04	2.1E-04	5.0E-05	3.3E-04
84	Sucrose	342.3	-2.25	1.6E-07	6.0E-07	5.2E-06	2.3E-06
85	Sufentanyl	387.5	4.59	5.7E-03	1.2E-02	1.2E-02	2.4E-02
86	Testosterone	288.4	3.31	3.8E-03	6.0E-03	4.0E-04	9.4E-03
87	*Thymol*	*150.2*	*3.34*	*2.1E-02*	*3.7E-02*	*5.2E-02*	*6.6E-02*
88	*2,4,6-Trichlorophenol*	*197.4*	*3.69*	*1.9E-02*	*3.5E-02*	*5.9E-02*	*6.2E-02*
89	*Water*	*18.01*	*-1.38*	*5.8E-05*	*1.5E-04*	*5.0E-04*	*3.9E-04*
90	3,4-Xylenol	122.2	2.35	7.4E-03	1.2E-02	3.6E-02	1.9E-02

EXHIBIT B-2

PREDICTED K_P FOR ORGANIC CONTAMINANTS IN WATER

Notes:

Chemicals with an asterisk (*) preceding them have been identified to be outside the effective prediction domain (EPD). EPD determination is calculated using the software package MLAB (Civilized Software, Inc., 8120 Woodmont Avenue, #250, Bethesda, MD 20814, USA).

Chemicals with two asterisks (**) are halogenated compounds. Because halogenated chemicals have a lower ratio of molar volume relative to their molecular weight than hydrocarbons (due to the relatively weighty halogen atom), the K_p correlation based on molecular weight of hydrocarbons will tend to underestimate permeability coefficients for halogenated organic chemicals. To address this problem, a new K_p correlation based on molar volume and log K_{ow} will be explored. In selecting the halogenated compounds, the focus was on trihalomethanes, the halogenated acids, and the halogenated aliphatics with halogenated molecules contributing to a large percentage of the molecular weight.

K_p is obtained from the modified Potts and Guy's equation (Equation 3.8). Values in the exhibit are obtained from the organic spreadsheet (ORG04_01.XLS) where the coefficients of Equation 3.8 carry more significant figures than shown in Chapter 3 and Appendix A.

95% LCL and UCL are calculated using the statistical software package STATA (STATA Corporation, 702 University Drive East, College Station, Texas 77840, USA). Compounds in italics are common to both the Flynn data set and the organic data set. For these compounds, the 95% LCL and UCL are obtained from Exhibit B-1 and common to both Exhibits B-1 and B-2.

All calculations were performed using the Lotus spreadsheet software, except where noted.

References:

Blank, I.H., and McAuliffe, D.J. (1985) Penetration of Benzene Through Human Skin. *J Invest Dermatol* 85: 522–526.

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Scheuplein, R.J. and Blank, I.H. (1973) Mechanism of Percutaneous Absorption. IV. Penetration of Nonelectrolytes (Alcohols) from Aqueous Solutions and from Pure Liquids. *J. Invest. Dermatol.* 60:286-326.

EXHIBIT B-2

PREDICTED K_p FOR ORGANIC CONTAMINANTS IN WATER (continued)

	CHEMICAL	CAS No.	MW	log K_{ow}	K_p 95% LCL	K_p (cm/hr) predicted	K_p (cm/hr) measured	K_p 95% UCL
1	Acetaldehyde	75070	44.1	-0.22	2.4E-05	6.3E-04		1.6E-02
2	Acetamide	60355	59	-1.26	3.9E-06	1.1E-04		2.9E-03
3	Acetylaminofluorene, 2-	53963	223	3.24	5.0E-04	1.2E-02		3.1E-01
4	Acrolein	107028	56.1	-0.10	2.5E-05	6.5E-04		1.7E-02
5	Acrylamide	79061	71	-0.67	8.5E-06	2.2E-04		5.9E-03
6	Acrylonitrile	107131	53.1	0.25	4.5E-05	1.2E-03		2.9E-02
7	Aldrin	309002	365	3.01	5.7E-05	1.4E-03		3.5E-02
** 8	Allyl chloride	107051	76.5	1.45	2.2E-04	5.4E-03		1.3E-01
9	Amino-2-methylanthraquinone, 1-	82280	237.3	2.80	2.2E-04	5.3E-03		1.3E-01
10	Aminoanthraquinone, 2-	117793	223	2.15	9.7E-05	2.4E-03		5.7E-02
11	Aminoazobenzene, p-	60093	197	2.62	2.8E-04	6.8E-03		1.7E-01
12	Aminoazotoluene, o-	97563	225.3	3.92	1.4E-03	3.4E-02		8.7E-01
13	Aminobiphenyl, 4-	92671	169.2	2.80	5.2E-04	1.3E-02		3.2E-01
14	Aniline	62533	93.1	0.90	7.5E-05	1.9E-03		4.7E-02
15	Anisidine, o-	90040	145	1.18	5.9E-05	1.5E-03		3.6E-02
16	Auramine	492808	267.4	3.54	4.5E-04	1.1E-02		2.8E-01
17	Benzene	71432	78.1	2.13	5.9E-04	1.5E-02	*1.1E-01* Blank and McAuliffe 1985	3.7E-01
18	Benzidine	92875	184.2	1.34	4.6E-05	1.1E-03		2.8E-02
* 19	Benzo-a-anthracene	56553	228.3	5.66	1.7E-02	4.7E-01		1.3E+01
* 20	Benzo-a-pyrene	50328	250	6.10	2.4E-02	7.0E-01		2.0E+01
* 21	Benzo-b-fluoranthene	205992	252.3	6.12	2.4E-02	7.0E-01		2.0E+01
22	Benzoic acid	65850	122	1.87	2.3E-04	5.7E-03		1.4E-01
23	Benzotrichloride	98077	195	2.92	4.5E-04	1.1E-02		2.7E-01
24	Benzyl chloride	100447	127	2.30	4.1E-04	1.0E-02		2.5E-01
25	Bis(2-chloroethyl)ether	111444	143	1.29	7.2E-05	1.8E-03		4.4E-02
** 26	Bromodichloromethane	75274	163.8	2.09	1.9E-04	4.6E-03		1.1E-01
** 27	Bromoform	75252	252.8	2.37	9.2E-05	2.2E-03		5.5E-02
** 28	Bromomethane	74839	95	1.19	1.1E-04	2.8E-03		7.0E-02
29	*Bromophenol, p-*	*106412*	*173*	*2.59*	*5.8E-03*	*8.8E-03*		*1.3E-02*
30	Butadiene, 1,3-	106990	54	1.99	6.5E-04	1.6E-02		4.1E-01
31	*2,3-Butanediol*	*513859*	*90.12*	*-0.92*	*5.2E-05*	*1.2E-04*	*4.0E-05 Blank et al. 1967*	*2.8E-04*
32	*n-Butanol*	*71363*	*74.12*	*0.88*	*1.3E-03*	*2.3E-03*	*2.5E-03 Scheuplein and Blank 1973*	*4.0E-03*
33	Butoxyethanol, 2-	111762	118	0.83	4.9E-05	1.2E-03		3.0E-02
34	Captan	133062	300	2.35	4.8E-05	1.2E-03		2.9E-02
35	Carbon disulfide	75150	80	2.24	6.9E-04	1.7E-02		4.3E-01
** 36	Carbon tetrachloride	56235	153.8	2.83	6.6E-04	1.6E-02		4.0E-01

EXHIBIT B-2

PREDICTED K_p FOR ORGANIC CONTAMINANTS IN WATER (continued)

	CHEMICAL	CAS No.	MW	log K_{ow}	K_p 95% LCL	K_p (cm/hr) predicted	K_p (cm/hr) measured	K_p 95% UCL
37	Chlordane	57749	409.8	5.54	1.4E-03	3.8E-02		1.0E+00
38	Chlordane (cis)	5103719	410	5.47	1.2E-03	3.4E-02		9.2E-01
39	Chlordane (trans)	5103742	410	5.47	1.2E-03	3.4E-02		9.2E-01
40	Chlorobenzene	108907	112.6	2.84	1.1E-03	2.8E-02		7.1E-01
41	*4-Chlorocresol*	*59507*	*142.6*	*3.10*	*1.7E-02*	*2.9E-02*	*5.5E-02 Roberts et al. 1977*	*4.9E-02*
** 42	Chlorodibromomethane	124481	208.3	2.23	1.3E-04	3.2E-03		7.9E-02
** 43	Chloroethane	75003	64.5	1.43	2.4E-04	6.1E-03		1.5E-01
** 44	Chloroform	67663	119.4	1.97	2.8E-04	6.8E-03	*1.4E-01* Nakai et al. 1999	1.7E-01
** 45	Chloromethane	74873	50.5	0.91	1.3E-04	3.3E-03		8.3E-02
46	*2-Chlorophenol*	*95578*	*128.6*	*2.15*	*5.2E-03*	*8.0E-03*	*3.3E-02 Roberts et al. 1977*	*1.2E-02*
47	*4-Chlorophenol*	*106489*	*128.6*	*2.39*	*7.3E-03*	*1.2E-02*	*3.6E-02 Roberts et al. 1977*	*1.8E-02*
48	Chlorothalonil	1897456	265.9	3.86	7.4E-04	1.9E-02		4.7E-01
* 49	Chrysene	218019	228.3	5.66	1.7E-02	4.7E-01		1.3E+01
50	Cresidine, p-	120718	137.2	1.67	1.4E-04	3.4E-03		8.4E-02
51	*m-Cresol*	*108394*	*108.1*	*1.96*	*4.9E-03*	*7.8E-03*	*1.5E-02 Roberts et al. 1977*	*1.2E-02*
52	*o-Cresol*	*95487*	*108.1*	*1.95*	*4.8E-03*	*7.7E-03*	*1.6E-02 Roberts et al. 1977*	*1.2E-02*
53	*p-Cresol*	*106445*	*108.1*	*1.95*	*4.8E-03*	*7.7E-03*	*1.8E-02 Roberts et al. 1977*	*1.2E-02*
* 54	DDD	72548	320	5.80	6.4E-03	1.8E-01		5.0E+00
* 55	DDE	72559	318	5.69	5.6E-03	1.6E-01		4.3E+00
* 56	DDT	50293	355	6.36	9.2E-03	2.7E-01		7.8E+00
** 57*	*n-Decanol*	*112301*	*158.3*	*4.57*	*9.5E-02*	*2.2E-01*	*7.9E-02 Scheuplein and Blank 1973*	*5.1E-01*
58	Di-2-ethylhexyl phthalate	117817	391	5.11	9.4E-04	2.5E-02		6.6E-01
59	Diaminoanisole, 2,4-	615054	138.2	-0.12	8.5E-06	2.2E-04		5.6E-03
60	Diaminotoluene	95807	122	0.34	2.2E-05	5.4E-04		1.4E-02
61	Diaminotoluene, 2,4-	101804	200	2.06	1.1E-04	2.8E-03		6.7E-02
* 62	Dibenzo(a,h)anthracene	53703	278.4	6.84	4.9E-02	1.5E+00		4.7E+01
63	Dibutyl phthalate	84742	278	4.13	9.4E-04	2.4E-02		6.1E-01
64	Dichlorobenzene, 1,2-	95501	147	3.38	1.6E-03	4.1E-02		1.0E+00
65	Dichlorobenzene, 1,3-	541731	147	3.60	2.3E-03	5.8E-02		1.5E+00
66	Dichlorobenzene, 1,4-	106467	147	3.39	1.7E-03	4.2E-02		1.1E+00
67	Dichlorobenzidine, 3,3'	91941	253.1	3.51	5.1E-04	1.3E-02		3.2E-01
** 68	Dichlorodifluoromethane	75718	120.9	2.16	3.6E-04	9.0E-03		2.2E-01
** 69	Dichloroethane, 1,1-	75343	99	1.79	2.7E-04	6.7E-03		1.7E-01
** 70	Dichloroethane, 1,2-	107062	99	1.48	1.7E-04	4.2E-03		1.0E-01
** 71	Dichloroethylene, 1,1-	75354	96.9	2.13	4.7E-04	1.2E-02		2.9E-01
** 72	Dichloroethylene, 1,2-(trans)	540590	96.9	1.86	3.1E-04	7.7E-03		1.9E-01
73	*2,4-Dichlorophenol*	*120832*	*163*	*3.06*	*1.2E-02*	*2.1E-02*	*6.0E-02 Roberts et al. 1977*	*3.4E-02*
** 74	Dichloropropane, 1,2-	78875	113	2.00	3.1E-04	7.8E-03		1.9E-01

EXHIBIT B-2

PREDICTED K_p FOR ORGANIC CONTAMINANTS IN WATER (continued)

	CHEMICAL	CAS No.	MW	log K_{ow}	K_p 95% LCL	K_p (cm/hr) predicted	K_p (cm/hr) measured	K_p 95% UCL
** 75	Dichloropropene, 1,3-	542756	111	1.60	1.7E-04	4.3E-03		1.1E-01
76	Dichlorvos	62737	221	1.47	3.5E-05	8.5E-04		2.1E-02
77	Dieldrin	60571	381	4.56	4.7E-04	1.2E-02		3.2E-01
78	Diepoxybutane	1464535	86.1	-1.84	1.1E-06	3.1E-05		8.7E-04
79	Diethyl phthalate	84662	222	2.47	1.6E-04	3.9E-03		9.5E-02
80	Diethyl sulfate	64675	154	1.14	5.0E-05	1.2E-03		3.0E-02
81	Dimethoxybenzidine, 3,3'-	119904	254.4	1.81	3.8E-05	9.3E-04		2.3E-02
82	Dimethyl phthalate	131113	194	1.56	5.7E-05	1.4E-03		3.4E-02
83	Dimethyl sulfate	77781	126	1.16	7.3E-05	1.8E-03		4.5E-02
84	Dimethylamine, n-nitroso-	62759	74.1	-0.57	9.6E-06	2.5E-04		6.6E-03
85	Dimethylaminoazobenzene, 4-	60117	225	4.58	3.6E-03	9.5E-02		2.5E+00
86	Dimethylbenzidine, 3,3'-	119937	212.3	2.34	1.5E-04	3.6E-03		8.8E-02
87	Dimethylcarbamyl chloride	79447	107.5	0.00	4.9E-06	3.9E-04		3.4E-03
88	Dimethylhydrazine, 1,1-	57147	60	-1.50	2.6E-06	7.3E-05		2.0E-03
89	Dimethylphenol, 2,4-	105679	122.2	2.30	4.4E-04	1.1E-02		2.7E-01
90	Dimethylphenol, 3,4-	95658	122	2.23	4.0E-04	9.8E-03		2.4E-01
91	Dinitrophenol, 2,4-	51285	184.1	1.54	6.3E-05	1.5E-03		3.7E-02
92	Dinitrotoluene, 2,4-	121142	182.1	1.98	1.3E-04	3.1E-03		7.5E-02
93	Dinitrotoluene, 2,6-	606202	182.1	1.72	8.5E-05	2.1E-03		5.1E-02
94	Dioxane, 1,4-	123911	88.1	-0.27	1.3E-05	3.3E-04		8.6E-03
95	Diphenylamine, n-nitroso-	86306	198.2	3.13	5.9E-04	1.5E-02		3.6E-01
96	Diphenylhydrazine, 1,2-	122667	184.2	2.94	5.3E-04	1.3E-02		3.2E-01
97	Dipropylamine, n-nitroso-	621647	130.2	1.36	9.5E-05	2.3E-03		5.8E-02
98	Endrin	72208	381	4.56	4.7E-04	1.2E-02		3.2E-01
99	Epichlorohydrin	106898	92	-0.21	1.3E-05	3.5E-04		8.9E-03
100	*Ethanol*	*64175*	*46.07*	*-0.31*	*2.6E-04*	*5.4E-04*	*7.9E-04 Scheuplein and Blank 1973*	*1.1E-03*
101	Ethanol, 2-(2-butoxyethoxy)-	112345	162	-0.92	1.8E-06	4.7E-05		1.3E-03
102	Ethanol, 2-(2-ethoxyethoxy)-	111900	134	-0.08	9.6E-06	2.5E-04		6.3E-03
103	Ethanol, 2-(2-methoxyethoxy)-	111773	120	-0.42	6.7E-06	1.7E-04		4.5E-03
104	*2-Ethoxy ethanol (Cellosolve)*	*110805*	*90.12*	*-0.32*	*1.5E-04*	*3.0E-04*		*6.1E-04*
105	Ethoxyethyl acetate, 2-	111159	132	0.65	3.1E-05	7.7E-04		1.9E-02
106	Ethyl acrylate	140885	100	1.32	1.3E-04	3.2E-03		8.0E-02
107	Ethyl carbamate	51796	89	-0.15	1.5E-05	3.9E-04		1.0E-02
108	*Ethyl ether*	*60297*	*74.12*	*0.89*	*1.4E-03*	*2.3E-03*	*1.6E-02 Blank et al. 1967*	*4.0E-03*
109	Ethylbenzene	100414	106.2	3.15	1.9E-03	4.9E-02		1.2E+00

EXHIBIT B-2

PREDICTED K_p FOR ORGANIC CONTAMINANTS IN WATER (continued)

	CHEMICAL	CAS No.	MW	log K_{ow}	K_p 95% LCL	K_p (cm/hr) predicted	K_p (cm/hr) measured	K_p 95% UCL
110	Ethylene oxide	75218	44.1	-0.30	2.2E-05	5.6E-04		1.5E-02
** 111	Ethylenedibromide	106934	188	1.96	1.1E-04	2.8E-03		6.8E-02
112	Ethyleneimine	151564	43	-1.12	6.0E-06	1.6E-04		4.4E-03
113	Ethylenethiourea	96457	96	-0.66	6.3E-06	1.7E-04		4.3E-03
114	*4-Ethylphenol*	*123079*	*122.2*	*2.58*	*1.0E-02*	*1.7E-02*	*3.5E-02 Roberts et al. 1977*	*2.7E-02*
* 115	Fluoranthene	206440	202.3	4.95	8.3E-03	2.2E-01		6.0E+00
116	Formaldehyde	50000	30	0.35	7.1E-05	1.8E-03		4.6E-02
117	Glycerol	56815	92.1	-1.76	1.1E-06	3.2E-05		9.1E-04
118	Heptachlor	76448	373.5	4.27	3.4E-04	8.6E-03		2.2E-01
119	*n-Heptanol*	*111706*	*116.2*	*2.62*	*1.2E-02*	*1.9E-02*	*3.2E-02*	*3.2E-02*
* 120	Hexachlorobenzene	118741	284.8	5.31	4.9E-03	1.3E-01		3.6E+00
** 121	Hexachlorobutadiene	87683	260.8	4.78	3.1E-03	8.1E-02		2.1E+00
** 122	Hexachloroethane	67721	236.7	3.93	1.2E-03	3.0E-02		7.6E-01
123	Hexamethylphosphoramide	680319	179	0.03	6.4E-06	1.6E-04		4.1E-03
124	*n-Hexanol*	*111273*	*102.2*	*2.03*	*5.8E-03*	*9.3E-03*	*1.3E-02*	*1.5E-02*
* 125	Hydrazine/Hydrazine sulfate	302012	32	-2.07	1.5E-06	4.4E-05		1.3E-03
* 126	Indeno(1,2,3-CD)pyrene	193395	276.3	6.58	3.5E-02	1.0E+00		3.1E+01
127	Isophorone	78591	138.2	1.67	1.4E-04	3.4E-03		8.3E-02
128	Lindane	58899	291	3.72	4.3E-04	1.1E-02		2.7E-01
129	Mechlorethamine	51752	156	1.07	4.4E-05	1.1E-03		2.6E-02
130	*Methanol*	*67561*	*32.04*	*-0.77*	*1.4E-04*	*3.2E-04*	*5.0E-04 Scheuplein and Blank 1973*	*7.3E-04*
131	Methoxyethanol, 2-	109864	76	-0.77	6.8E-06	1.8E-04		4.8E-03
132	Methoxypropan-2-ol, 1-	107982	90	-0.18	1.4E-05	3.7E-04		9.6E-03
133	Methyl ethyl ketone	78933	72	0.29	3.8E-05	9.6E-04		2.4E-02
134	*Methyl-4-hydroxy benzoate*	*99763*	*152.1*	*1.96*	*3.0E-03*	*4.4E-03*	*9.1E-03 Roberts et al. 1977*	*6.5E-03*
** 135	Methyl iodide	74884	142	1.51	1.0E-04	2.5E-03		6.2E-02
136	Methylaziridine, 2-	75558	57	-0.60	1.1E-05	3.0E-04		7.9E-03
137	Methylene bis(2-chloroaniline), 4,4'-	101144	267.2	3.94	8.2E-04	2.1E-02		5.2E-01
138	Methylene bis(N,N'-dimethyl)aniline, 4,4'-	101611	254	4.75	3.2E-03	8.4E-02		2.2E+00
** 139	Methylene chloride	75092	84.9	1.25	1.4E-04	3.5E-03		8.8E-02
140	Methylenedianiline, 4,4'-	101779	198	1.59	5.7E-05	1.4E-03		3.4E-02
141	Michler's ketone	90948	268.4	4.07	9.8E-04	2.5E-02		6.3E-01
** 142	Mustard Gas	505602	159.1	2.03	1.8E-04	4.5E-03		1.1E-01
143	Naphthalene	91203	128.2	3.30	1.8E-03	4.7E-02		1.2E+00

EXHIBIT B-2

PREDICTED K_p FOR ORGANIC CONTAMINANTS IN WATER (continued)

	CHEMICAL	CAS No.	MW	log K_{ow}	K_p 95% LCL	K_p (cm/hr) predicted	K_p (cm/hr) measured	K_p 95% UCL
144	*2-Naphthol*	*135193*	*144.2*	*2.84*	*1.1E-02*	*1.9E-02*	*2.8E-02 Roberts et al. 1977*	*3.1E-02*
145	Naphthylamine, 1-	134327	143.2	2.25	3.1E-04	7.7E-03		1.9E-01
146	Naphthylamine, 2-	91598	143.2	2.28	3.3E-04	8.1E-03		2.0E-01
147	Nitrilotriacetic acid	139139	191	-0.18	3.9E-06	1.0E-04		2.6E-03
148	Nitro-o-anisidine, 5-	99592	152.7	1.47	8.4E-05	2.1E-03		5.1E-02
149	Nitrobiphenyl, 4-	92933	199.2	3.77	1.5E-03	3.8E-02		9.7E-01
* 150	Nitrofen	1836755	284.1	5.53	6.8E-03	1.9E-01		5.2E+00
151	Nitrophenol, 2-	88755	139.1	1.79	1.6E-04	4.0E-03		9.9E-02
152	Nitrophenol, 2-amino-4-	99570	154.1	1.36	7.0E-05	1.7E-03		4.2E-02
153	*3-Nitrophenol*	*554847*	*139.1*	*2.00*	*3.7E-03*	*5.5E-03*	*5.6E-03 Roberts et al. 1977*	*8.4E-03*
154	*4-Nitrophenol*	*100027*	*139.1*	*1.91*	*3.2E-03*	*4.8E-03*	*5.6E-03 Roberts et al. 1977*	*7.3E-03*
155	Nitrophenol, 4-amino-2-	119346	154.1	0.96	3.8E-05	9.3E-04		2.3E-02
156	Nitropropane, 2-	79469	110	0.55	3.5E-05	8.8E-04		2.2E-02
157	Nitroso-di-n-butylamine, n-	924163	158.2	1.92	1.6E-04	3.8E-03		9.4E-02
158	Nitroso-N-ethylurea, n-	759739	117.1	0.23	1.9E-05	4.9E-04		1.2E-02
159	Nitroso-N-methylurea, n-	684935	103.1	-0.03	1.5E-05	3.9E-04		1.0E-02
160	Nitrosodiethanolamine, n-	1116547	134	-1.58	8.9E-07	2.5E-05		6.9E-04
161	Nitrosodiethylamine, n-	55185	88	0.48	4.2E-05	1.0E-03		2.6E-02
162	Nitrosodiphenylamine, p-	156105	198.2	3.50	1.0E-03	2.6E-02		6.4E-01
163	Nitrosomethylvinylamine, n-	4549400	86.1	0.00	2.0E-05	5.1E-04		1.3E-02
164	Nitrosomorpholine, n-	59892	116.1	-0.44	6.9E-06	1.8E-04		4.6E-03
165	Nitrosonornicotine, n-	16543558	177.2	0.03	6.5E-06	1.7E-04		4.2E-03
166	Nitrosopiperidine, n-	100754	350.3	0.36	1.1E-06	2.9E-05		7.6E-04
167	*n-Nonanol*	*143088*	*144.3*	*3.77*	*4.0E-02*	*7.8E-02*	*6.0E-02 Scheuplein and Blank 1973*	*1.5E-01*
168	*n-Octanol*	*111875*	*130.2*	*2.97*	*1.6E-02*	*2.7E-02*	*5.2E-02 Scheuplein and Blank 1973*	*4.7E-02*
169	Parathion	56382	291	3.83	5.1E-04	1.3E-02		3.2E-01
* 170	PCB-chlorobiphenyl, 4-	2051629	292	6.50	2.5E-02	7.5E-01		2.2E+01
* 171	PCB-hexachlorobiphenyl	26601649	361	6.72	1.4E-02	4.3E-01		1.3E+01
** 172	Pentachloronitrobenzene	82688	295.3	4.64	1.6E-03	4.2E-02		1.1E+00
* 173	Pentachlorophenol	87865	266.4	5.86	1.4E-02	3.9E-01		1.1E+01
174	*n-Pentanol*	*71410*	*88.15*	*1.56*	*3.4E-03*	*5.5E-03*	*6.0E-03 Scheuplein and Blank 1973*	*8.9E-03*
175	Pentanone, 4-methyl-2-	108101	100	1.19	1.1E-04	2.7E-03		6.6E-02
* 176	Phenanthrene	85018	178.2	4.46	5.5E-03	1.4E-01		3.8E+00
177	*Phenol*	*108952*	*94.11*	*1.46*	*2.7E-03*	*4.3E-03*	*8.1E-03 Roberts et al. 1977*	*7.0E-03*
178	Phenol, 4,6-dinitro-2-methyl-	534521	198.1	2.12	1.3E-04	3.1E-03		7.6E-02

EXHIBIT B-2

PREDICTED K_p FOR ORGANIC CONTAMINANTS IN WATER (continued)

	CHEMICAL	CAS No.	MW	log K_{ow}	K_p 95% LCL	K_p (cm/hr) predicted	K_p (cm/hr) measured	K_p 95% UCL
179	*n-Propanol*	*71238*	*60.1*	*0.25*	*5.6E-04*	*1.1E-03*	*1.4E-03*	*2.0E-03*
180	Propiolactone, beta-	57578	72	-0.46	1.2E-05	3.1E-04		8.0E-03
181	Propylene oxide	75569	58.1	0.03	3.0E-05	7.7E-04		2.0E-02
182	*Resorcinol*	*108463*	*110.1*	*0.80*	*7.7E-04*	*1.3E-03*	*2.4E-04 Roberts et al. 1977*	*2.1E-03*
183	Safrole	94597	162.2	2.66	4.6E-04	1.1E-02		2.8E-01
184	Styrene	100425	104.1	2.95	1.5E-03	3.7E-02		9.4E-01
185	Styrene oxide	96093	120	1.61	1.6E-04	3.9E-03		9.6E-02
* 186	TCDD	1746016	322	6.80	2.7E-02	8.1E-01		2.5E+01
** 187	Tetrachlorethylene	127184	165.8	3.40	1.3E-03	3.3E-02	*1.8E-02* Nakai et al. 1999	8.4E-01
** 188	Tetrachloroethane, 1,1,2,2-	79345	167.9	2.39	2.8E-04	6.9E-03		1.7E-01
189	Thioacetamide	62555	75	0.71	7.0E-05	1.8E-03		4.4E-02
190	Thiodianiline, 4,4'-	139651	216	2.03	8.8E-05	2.1E-03		5.2E-02
191	Thiourea	62566	76	-0.95	5.1E-06	1.4E-04		3.7E-03
192	*Thymol*	*89838*	*150.2*	*3.34*	*2.1E-02*	*3.7E-02*	*5.2E-02 Roberts et al. 1977*	*6.6E-02*
193	Toluene	108883	92.1	2.73	1.2E-03	3.1E-02		7.8E-01
194	Toluidine hydrochloride, o-	636215	143.2	1.29	7.2E-05	1.8E-03		4.4E-02
195	Toluidine, o-	95534	107	1.32	1.2E-04	3.0E-03		7.3E-02
196	Toxaphene	8001352	414	4.82	4.5E-04	1.2E-02		3.1E-01
197	Trichlorobenzene, 1,2,4-	120821	181.5	3.98	2.6E-03	6.6E-02		1.7E+00
** 198	Trichloroethane, 1,1,1-	71556	133.4	2.49	5.1E-04	1.3E-02		3.1E-01
** 199	Trichloroethane, 1,1,2-	79005	133.4	2.05	2.6E-04	6.4E-03		1.6E-01
** 200	Trichloroethylene	79016	131.4	2.42	4.7E-04	1.2E-02	*1.2E-01* Nakai et al. 1999	2.9E-01
** 201	Trichlorofluoromethane	75694	137.4	2.53	5.1E-04	1.3E-02		3.2E-01
202	*2,4,6-Trichlorophenol*	*88062*	*197.4*	*3.69*	*1.9E-02*	*3.5E-02*	*5.9E-02 Roberts et al. 1977*	*6.2E-02*
* 203	Tris(2,3-dibromopropyl)phosphate	126727	697.6	4.98	1.3E-05	3.9E-04		1.1E-02
204	Tris(aziridinyl)-para-benzoquinone	68768	231.3	-1.34	3.7E-07	1.0E-05		2.8E-04
* 205	Urea	57136	60	-2.11	9.9E-07	2.9E-05		8.3E-04
** 206	Vinyl bromide	593602	107	1.57	1.8E-04	4.3E-03		1.1E-01
** 207	Vinyl chloride	75014	62.5	1.36	2.2E-04	5.6E-03		1.4E-01
** 208*	*Water*	*7732185*	*18.01*	*-1.38*	*5.8E-05*	*1.5E-04*	*5.0E-04*	*3.9E-04*
209	Xylene, m-	108383	106.2	3.20	2.1E-03	5.3E-02		1.4E+00

EXHIBIT B-3

CALCULATION OF DERMAL ABSORBED DOSE FOR ORGANIC CHEMICALS IN WATER

Notes:

The following default exposure conditions are used to calculate exposure to chemicals in water through showering, assuming carcinogenic effects. Site-specific exposure conditions should be used in the spreadsheet ORG04_01.XLS for appropriate health effects (cancer or noncancer).

Concentration in ppb (1 ppb = 1 µg/L x mg/1000 µg x L/1000 cm^3):
Conc = 1 ppm = 1000 ppb = 1000 µg/L = 1 mg/L = 10^{-3} mg/cm^3 (default value for purpose of illustration)
(site-specific concentration should be used in actual calculations)
Surface area exposed (cm^2): SA = 18000 cm^2
Event time (hr/event): t_{event} = 0.58 hr/event (35 minutes/event)
Event frequency (events/day): EV = 1.0 event/day
Exposure frequency (days/year): EF = 350.0 days/yr
Exposure duration (years): ED = 30.0 years
Body weight (kg): BW = 70.0 kg
Averaging time (days): AT = 25550 days
for carcinogenic effects, AT = 70 years (25550 days)
for noncarcinogenic effects, AT = ED (in days)
Skin thickness (assumed to be 10 µm): l_{sc} = 10^{-3} cm
Time to reach steady-state (hr): t* is chemical-specific
Fraction absorbed (FA, from Exhibit A-5, to the nearest one significant figure)
K_p used in the calculation of DA_{event} is the K_p predicted for all chemicals

Default conditions for screening purposes: compare Dermal adults (showering for 35 minutes per day) to Oral adults (drinking 2 liters of water per day)
DAD (mg/day) = DA_{event} x SA x EV
Oral Dose (mg/day) = Conc x IR x ABS_{GI}
IR: Ingestion rate of drinking water = 2000 (cm^3/day = L/day x 1000 cm^3/L)
ABS_{GI}: Absorption fraction in GI tract = 1.0 (assuming 100% GI absorption)

The spreadsheet (ORG04_01.XLS) also provides the calculation of the ratio of the dermal dose absorbed to the total dose available from a showering scenario, assuming 5 gallons/minute as a flow rate. Refer to Chapter 3 and Appendix A for equations to evaluate DA_{event} and DAD.

All calculations were performed using the Lotus spreadsheet software, except otherwise noted.

EXHIBIT B-3

CALCULATION OF DERMAL ABSORBED DOSE FOR ORGANIC CHEMICALS IN WATER (continued)

NA: The abbreviation NA (not applicable) in the "Chem Assess" column reflects OSWER's recommendation against quantifying exposure and risk in the body of the risk assessment because these contaminants are outside the effective predictive domain.

Y/N: The abbreviation Y (yes) and N (no) in the "Chem Assess" column refers to whether or not dermal exposure exceeds 10% of drinking water— The actual ratio dermal/oral is given in the column labeled "Derm/Oral," and the next column labeled "Chem Assess" gives the result of the comparison of these two routes of exposure as "Y" (yes) when dermal exposure exceeds 10% of drinking water (ratio of DAD from dermal to oral). The oral route is represented by drinking 2 liters of water per day.

*/** See notes provided at the beginning of Exhibit B-2.

	CHEMICAL	CAS No.	K_p (cm/hr)	B	τ (hr)	t* (hr)	FA	DA_{event} (mg/cm^2-event)	DAD (mg/kg-day)	Derm/ Oral (%)	Chem Assess
1	Acetaldehyde	75070	6.3E-04	0.0	0.19	0.45	1.0	6.1E-07	6.4E-05	1%	N
2	Acetamide	60355	1.1E-04	0.0	0.23	0.55	1.0	1.1E-07	1.2E-05	0%	N
3	Acetylaminofluorene, 2-	53963	1.2E-02	0.1	1.90	4.56	1.0	3.6E-05	3.8E-03	33%	Y
4	Acrolein	107028	6.5E-04	0.0	0.22	0.53	1.0	6.7E-07	7.0E-05	1%	N
5	Acrylamide	79061	2.2E-04	0.0	0.27	0.64	1.0	2.4E-07	2.6E-05	0%	N
6	Acrylonitrile	107131	1.2E-03	0.0	0.21	0.51	1.0	1.2E-06	1.2E-04	1%	N
7	Aldrin	309002	1.4E-03	0.0	11.89	28.54	1.0	1.0E-05	1.1E-03	9%	N
** 8	Allyl chloride	107051	5.4E-03	0.0	0.29	0.69	1.0	6.1E-06	6.4E-04	5%	N
9	Amino-2-methylanthraquinone, 1-	82280	5.3E-03	0.0	2.28	5.48	1.0	1.7E-05	1.8E-03	15%	Y
10	Aminoanthraquinone, 2-	117793	2.4E-03	0.0	1.90	4.56	1.0	6.9E-06	7.2E-04	6%	N
11	Aminoazobenzene, p-	60093	6.8E-03	0.0	1.36	3.26	1.0	1.7E-05	1.8E-03	15%	Y
12	Aminoazotoluene, o-	97563	3.4E-02	0.2	1.96	4.69	1.0	1.0E-04	1.1E-02	91%	Y
13	Aminobiphenyl, 4-	92671	1.3E-02	0.1	0.95	2.27	1.0	2.6E-05	2.8E-03	24%	Y
14	Aniline	62533	1.9E-03	0.0	0.35	0.85	1.0	2.3E-06	2.5E-04	2%	N
15	Anisidine, o-	90040	1.5E-03	0.0	0.69	1.66	1.0	2.6E-06	2.7E-04	2%	N
16	Auramine	492808	1.1E-02	0.1	3.37	8.09	0.9	3.9E-05	4.1E-03	35%	Y
17	Benzene	71432	1.5E-02	0.1	0.29	0.70	1.0	1.7E-05	1.8E-03	15%	Y
18	Benzidine	92875	1.1E-03	0.0	1.15	2.76	1.0	2.6E-06	2.7E-04	2%	N
* 19	Benzo-a-anthracene	56553	4.7E-01	2.8	2.03	8.53	1.0	1.4E-03	1.5E-01	1283%	NA
* 20	Benzo-a-pyrene	50328	7.0E-01	4.3	2.69	11.67	1.0	2.4E-03	2.6E-01	2186%	NA
* 21	Benzo-b-fluoranthene	205992	7.0E-01	4.3	2.77	12.03	1.0	2.5E-03	2.6E-01	2221%	NA
22	Benzoic acid	65850	5.7E-03	0.0	0.51	1.24	1.0	8.6E-06	9.1E-04	8%	N
23	Benzotrichloride	98077	1.1E-02	0.1	1.32	3.17	1.0	2.7E-05	2.8E-03	24%	Y
24	Benzyl chloride	100447	1.0E-02	0.0	0.55	1.32	1.0	1.6E-05	1.7E-03	14%	Y
25	Bis(2-chloroethyl)ether	111444	1.8E-03	0.0	0.68	1.62	1.0	3.1E-06	3.3E-04	3%	N
** 26	Bromodichloromethane	75274	4.6E-03	0.0	0.88	2.12	1.0	9.2E-06	9.7E-04	8%	N
** 27	Bromoform	75252	2.2E-03	0.0	2.79	6.70	1.0	7.9E-06	8.4E-04	7%	N
** 28	Bromomethane	74839	2.8E-03	0.0	0.36	0.87	1.0	3.6E-06	3.8E-04	3%	N

EXHIBIT B-3

CALCULATION OF DERMAL ABSORBED DOSE FOR ORGANIC CHEMICALS IN WATER (continued)

	CHEMICAL	CAS No.	K_p (cm/hr)	B	τ (hr)	t* (hr)	FA	DA_{event} (mg/cm^2-event)	DAD (mg/kg-day)	Derm/ Oral (%)	Chem Assess
29	Bromophenol, p-	106412	8.8E-03	0.0	1.00	2.39	1.0	1.9E-05	2.0E-03	17%	Y
30	Butadiene, 1,3-	106990	1.6E-02	0.0	0.21	0.51	1.0	1.6E-05	1.7E-03	15%	Y
31	2,3-Butanediol	513859	1.2E-04	0.0	0.34	0.82	1.0	1.5E-07	1.6E-05	0%	N
32	n-Butanol	71363	2.3E-03	0.0	0.28	0.67	1.0	2.6E-06	2.7E-04	2%	N
33	Butoxyethanol, 2-	111762	1.2E-03	0.0	0.49	1.17	1.0	1.8E-06	1.9E-04	2%	N
34	Captan	133062	1.2E-03	0.0	5.13	12.32	1.0	5.7E-06	6.0E-04	5%	N
35	Carbon disulfide	75150	1.7E-02	0.1	0.30	0.72	1.0	2.0E-05	2.1E-03	18%	Y
** 36	Carbon tetrachloride	56235	1.6E-02	0.1	0.78	1.86	1.0	3.0E-05	3.2E-03	27%	Y
37	Chlordane	57749	3.8E-02	0.3	21.21	50.91	0.7	2.6E-04	2.7E-02	231%	Y
38	Chlordane (cis)	5103719	3.4E-02	0.3	21.27	51.05	0.7	2.3E-04	2.4E-02	208%	Y
39	Chlordane (trans)	5103742	3.4E-02	0.3	21.27	51.05	0.7	2.3E-04	2.4E-02	208%	Y
40	Chlorobenzene	108907	2.8E-02	0.1	0.46	1.09	1.0	4.0E-05	4.2E-03	36%	Y
41	4-Chlorocresol	59507	2.9E-02	0.1	0.67	1.61	1.0	4.9E-05	5.2E-03	44%	Y
** 42	Chlorodibromomethane	124481	3.2E-03	0.0	1.57	3.77	1.0	8.5E-06	9.0E-04	8%	N
** 43	Chloroethane	75003	6.1E-03	0.0	0.24	0.59	1.0	6.3E-06	6.7E-04	6%	N
** 44	Chloroform	67663	6.8E-03	0.0	0.50	1.19	1.0	1.0E-05	1.1E-03	9%	N
** 45	Chloromethane	74873	3.3E-03	0.0	0.20	0.49	1.0	3.3E-06	3.4E-04	3%	N
46	2-Chlorophenol	95578	8.0E-03	0.0	0.56	1.34	1.0	1.3E-05	1.3E-03	11%	Y
47	4-Chlorophenol	106489	1.2E-02	0.1	0.56	1.34	1.0	1.8E-05	1.9E-03	16%	Y
48	Chlorothalonil	1897456	1.9E-02	0.1	3.30	7.93	0.9	6.4E-05	6.8E-03	58%	Y
* 49	Chrysene	218019	4.7E-01	2.8	2.03	8.53	1.0	1.4E-03	1.5E-01	1283%	NA
50	Cresidine, p-	120718	3.4E-03	0.0	0.63	1.50	1.0	5.7E-06	6.0E-04	5%	N
51	m-Cresol	108394	7.8E-03	0.0	0.43	1.03	1.0	1.1E-05	1.1E-03	10%	N
52	o-Cresol	95487	7.7E-03	0.0	0.43	1.03	1.0	1.1E-05	1.1E-03	10%	N
53	p-Cresol	106445	7.7E-03	0.0	0.43	1.03	1.0	1.1E-05	1.1E-03	10%	N
* 54	DDD	72548	1.8E-01	1.2	6.65	25.99	0.8	7.8E-04	8.3E-02	703%	NA
* 55	DDE	72559	1.6E-01	1.1	6.48	25.08	0.8	6.7E-04	7.1E-02	602%	NA
* 56	DDT	50293	2.7E-01	1.9	10.45	42.51	0.7	1.3E-03	1.4E-01	1156%	NA
* 57	n-Decanol	112301	2.2E-01	1.1	0.82	3.18	1.0	4.2E-04	4.5E-02	380%	NA
58	Di-2-ethylhexyl phthalate	117817	2.5E-02	0.2	16.64	39.93	0.8	1.7E-04	1.8E-02	155%	Y
59	Diaminoanisole, 2,4-	615054	2.2E-04	0.0	0.63	1.52	1.0	3.7E-07	3.9E-05	0%	N
60	Diaminotoluene	95807	5.4E-04	0.0	0.51	1.24	1.0	8.3E-07	8.7E-05	1%	N
61	Diaminotoluene, 2,4-	101804	2.8E-03	0.0	1.41	3.38	1.0	6.9E-06	7.3E-04	6%	N
* 62	Dibenzo(a,h)anthracene	53703	1.5E+00	9.7	3.88	17.57	0.6	3.8E-03	4.0E-01	3388%	NA
63	Dibutyl phthalate	84742	2.4E-02	0.2	3.86	9.27	0.9	9.0E-05	9.5E-03	81%	Y
64	Dichlorobenzene, 1,2-	95501	4.1E-02	0.2	0.71	1.71	1.0	7.4E-05	7.8E-03	66%	Y
65	Dichlorobenzene, 1,3-	541731	5.8E-02	0.3	0.71	1.71	1.0	1.0E-04	1.1E-02	93%	Y
66	Dichlorobenzene, 1,4-	106467	4.2E-02	0.2	0.71	1.71	1.0	7.5E-05	7.9E-03	67%	Y

EXHIBIT B-3

CALCULATION OF DERMAL ABSORBED DOSE FOR ORGANIC CHEMICALS IN WATER (continued)

	CHEMICAL	CAS No.	K_p (cm/hr)	B	τ (hr)	t* (hr)	FA	DA_{event} (mg/cm^2-event)	DAD (mg/kg-day)	Derm/ Oral (%)	Chem Assess
67	Dichlorobenzidine, 3,3'	91941	1.3E-02	0.1	2.80	6.72	1.0	4.5E-05	4.8E-03	41%	Y
** 68	Dichlorodifluoromethane	75718	9.0E-03	0.0	0.51	1.22	1.0	1.3E-05	1.4E-03	12%	Y
** 69	Dichloroethane, 1,1-	75343	6.7E-03	0.0	0.38	0.92	1.0	8.8E-06	9.3E-04	8%	N
** 70	Dichloroethane, 1,2-	107062	4.2E-03	0.0	0.38	0.92	1.0	5.5E-06	5.8E-04	5%	N
** 71	Dichloroethylene, 1,1-	75354	1.2E-02	0.0	0.37	0.89	1.0	1.5E-05	1.6E-03	14%	Y
** 72	Dichloroethylene, 1,2-(trans)	540590	7.7E-03	0.0	0.37	0.89	1.0	9.9E-06	1.0E-03	9%	N
73	2,4-Dichlorophenol	120832	2.1E-02	0.1	0.87	2.10	1.0	4.1E-05	4.3E-03	37%	Y
** 74	Dichloropropane, 1,2-	78875	7.8E-03	0.0	0.46	1.10	1.0	1.1E-05	1.2E-03	10%	N
** 75	Dichloropropene, 1,3-	542756	4.3E-03	0.0	0.45	1.07	1.0	6.1E-06	6.4E-04	5%	N
76	Dichlorvos	62737	8.5E-04	0.0	1.85	4.44	1.0	2.5E-06	2.6E-04	2%	N
77	Dieldrin	60571	1.2E-02	0.1	14.62	35.09	0.8	7.9E-05	8.3E-03	71%	Y
78	Diepoxybutane	1464535	3.1E-05	0.0	0.32	0.78	1.0	3.7E-08	3.9E-06	0%	N
79	Diethyl phthalate	84662	3.9E-03	0.0	1.87	4.50	1.0	1.1E-05	1.2E-03	10%	Y
80	Diethyl sulfate	64675	1.2E-03	0.0	0.78	1.87	1.0	2.3E-06	2.4E-04	2%	N
81	Dimethoxybenzidine, 3,3'-	119904	9.3E-04	0.0	2.85	6.84	1.0	3.3E-06	3.5E-04	3%	N
82	Dimethyl phthalate	131113	1.4E-03	0.0	1.31	3.13	1.0	3.4E-06	3.5E-04	3%	N
83	Dimethyl sulfate	77781	1.8E-03	0.0	0.54	1.30	1.0	2.8E-06	3.0E-04	3%	N
84	Dimethylamine, n-nitroso-	62759	2.5E-04	0.0	0.28	0.67	1.0	2.8E-07	3.0E-05	0%	N
85	Dimethylaminoazobenzene, 4-	60117	9.5E-02	0.5	1.95	4.68	1.0	2.8E-04	2.9E-02	251%	Y
86	Dimethylbenzidine, 3,3'-	119937	3.6E-03	0.0	1.65	3.97	1.0	9.8E-06	1.0E-03	9%	N
87	Dimethylcarbamyl chloride	79447	3.9E-04	0.0	0.43	1.02	1.0	5.4E-07	5.7E-05	0%	N
88	Dimethylhydrazine, 1,1-	57147	7.3E-05	0.0	0.23	0.55	1.0	7.6E-08	8.0E-06	0%	N
89	Dimethylphenol, 2,4-	105679	1.1E-02	0.0	0.52	1.24	1.0	1.7E-05	1.7E-03	15%	Y
90	Dimethylphenol, 3,4-	95658	9.8E-03	0.0	0.51	1.24	1.0	1.5E-05	1.6E-03	13%	Y
91	Dinitrophenol, 2,4-	51285	1.5E-03	0.0	1.15	2.76	1.0	3.5E-06	3.7E-04	3%	N
92	Dinitrotoluene, 2,4-	121142	3.1E-03	0.0	1.12	2.69	1.0	6.9E-06	7.3E-04	6%	N
93	Dinitrotoluene, 2,6-	606202	2.1E-03	0.0	1.12	2.69	1.0	4.6E-06	4.9E-04	4%	N
94	Dioxane, 1,4-	123911	3.3E-04	0.0	0.33	0.80	1.0	4.0E-07	4.3E-05	0%	N
95	Diphenylamine, n-nitroso-	86306	1.5E-02	0.1	1.38	3.31	1.0	3.6E-05	3.8E-03	32%	Y
96	Diphenylhydrazine, 1,2-	122667	1.3E-02	0.1	1.15	2.76	1.0	3.0E-05	3.1E-03	27%	Y
97	Dipropylamine, n-nitroso-	621647	2.3E-03	0.0	0.57	1.37	1.0	3.7E-06	3.9E-04	3%	N
98	Endrin	72208	1.2E-02	0.1	14.62	35.09	0.8	7.9E-05	8.3E-03	71%	Y
99	Epichlorohydrin	106898	3.5E-04	0.0	0.35	0.84	1.0	4.3E-07	4.6E-05	0%	N

EXHIBIT B-3

CALCULATION OF DERMAL ABSORBED DOSE FOR ORGANIC CHEMICALS IN WATER (continued)

	CHEMICAL	CAS No.	K_p (cm/hr)	B	τ (hr)	t* (hr)	FA	DA_{event} (mg/cm^2-event)	DAD (mg/kg-day)	Derm/ Oral (%)	Chem Assess
100	Ethanol	64175	5.4E-04	0.0	0.19	0.46	1.0	5.2E-07	5.5E-05	0%	N
101	Ethanol, 2-(2-butoxyethoxy)-	112345	4.7E-05	0.0	0.86	2.07	1.0	9.3E-08	9.8E-06	0%	N
102	Ethanol, 2-(2-ethoxyethoxy)-	111900	2.5E-04	0.0	0.60	1.44	1.0	4.0E-07	4.2E-05	0%	N
103	Ethanol, 2-(2-methoxyethoxy)-	111773	1.7E-04	0.0	0.50	1.20	1.0	2.6E-07	2.8E-05	0%	N
104	2-Ethoxy ethanol (Cellosolve)	110805	3.0E-04	0.0	0.34	0.82	1.0	3.7E-07	3.9E-05	0%	N
105	Ethoxyethyl acetate, 2-	111159	7.7E-04	0.0	0.59	1.41	1.0	1.2E-06	1.3E-04	1%	N
106	Ethyl acrylate	140885	3.2E-03	0.0	0.39	0.93	1.0	4.3E-06	4.5E-04	4%	N
107	Ethyl carbamate	51796	3.9E-04	0.0	0.34	0.81	1.0	4.8E-07	5.1E-05	0%	N
108	Ethyl ether	60297	2.3E-03	0.0	0.28	0.67	1.0	2.6E-06	2.8E-04	2%	N
109	Ethylbenzene	100414	4.9E-02	0.2	0.42	1.01	1.0	6.7E-05	7.1E-03	61%	Y
110	Ethylene oxide	75218	5.6E-04	0.0	0.19	0.45	1.0	5.4E-07	5.7E-05	0%	N
**111	Ethylenedibromide	106934	2.8E-03	0.0	1.21	2.90	1.0	6.4E-06	6.8E-04	6%	N
112	Ethyleneimine	151564	1.6E-04	0.0	0.19	0.45	1.0	1.5E-07	1.6E-05	0%	N
113	Ethylenethiourea	96457	1.7E-04	0.0	0.37	0.88	1.0	2.1E-07	2.2E-05	0%	N
114	4-Ethylphenol	123079	1.7E-02	0.1	0.52	1.24	1.0	2.5E-05	2.7E-03	23%	Y
* 115	Fluoranthene	206440	2.2E-01	1.2	1.45	5.68	1.0	5.7E-04	6.0E-02	512%	NA
116	Formaldehyde	50000	1.8E-03	0.0	0.16	0.38	1.0	1.6E-06	1.7E-04	1%	N
117	Glycerol	56815	3.2E-05	0.0	0.35	0.84	1.0	4.0E-08	4.3E-06	0%	N
118	Heptachlor	76448	8.6E-03	0.1	13.27	31.85	0.8	5.3E-05	5.6E-03	48%	Y
119	n-Heptanol	111706	1.9E-02	0.1	0.48	1.15	1.0	2.8E-05	3.0E-03	25%	Y
* 120	Hexachlorobenzene	118741	1.3E-01	0.9	4.22	16.21	0.9	5.2E-04	5.5E-02	469%	NA
**121	Hexachlorobutadiene	87683	8.1E-02	0.5	3.09	7.42	0.9	2.7E-04	2.9E-02	243%	Y
**122	Hexachloroethane	67721	3.0E-02	0.2	2.27	5.44	1.0	9.6E-05	1.0E-02	86%	Y
123	Hexamethylphosphoramide	680319	1.6E-04	0.0	1.08	2.58	1.0	3.6E-07	3.8E-05	0%	N
124	n-Hexanol	111273	9.3E-03	0.0	0.40	0.96	1.0	1.2E-05	1.3E-03	11%	Y
* 125	Hydrazine/Hydrazine sulfate	302012	4.4E-05	0.0	0.16	0.39	1.0	3.9E-08	4.2E-06	0%	NA
* 126	Indeno(1,2,3-CD)pyrene	193395	1.0E+00	6.7	3.78	16.83	0.6	2.6E-03	2.7E-01	2307%	NA
127	Isophorone	78591	3.4E-03	0.0	0.63	1.52	1.0	5.7E-06	6.0E-04	5%	N
128	Lindane	58899	1.1E-02	0.1	4.57	10.97	0.9	4.4E-05	4.6E-03	40%	Y
129	Mechlorethamine	51752	1.1E-03	0.0	0.80	1.92	1.0	2.0E-06	2.1E-04	2%	N
130	Methanol	67561	3.2E-04	0.0	0.16	0.39	1.0	2.9E-07	3.0E-05	0%	N
131	Methoxyethanol, 2-	109864	1.8E-04	0.0	0.28	0.68	1.0	2.0E-07	2.1E-05	0%	N
132	Methoxypropan-2-ol, 1-	107982	3.7E-04	0.0	0.34	0.82	1.0	4.6E-07	4.8E-05	0%	N
133	Methyl ethyl ketone	78933	9.6E-04	0.0	0.27	0.65	1.0	1.1E-06	1.1E-04	1%	N

EXHIBIT B-3

CALCULATION OF DERMAL ABSORBED DOSE FOR ORGANIC CHEMICALS IN WATER (continued)

	CHEMICAL	CAS No.	K_p (cm/hr)	B	τ (hr)	t* (hr)	FA	DA_{event} (mg/cm^2-event)	DAD (mg/kg-day)	Derm/ Oral (%)	Chem Assess
134	Methyl-4-hydroxy benzoate	99763	4.4E-03	0.0	0.76	1.82	1.0	8.1E-06	8.6E-04	7%	N
**135	Methyl iodide	74884	2.5E-03	0.0	0.67	1.60	1.0	4.3E-06	4.6E-04	4%	N
136	Methylaziridine, 2-	75558	3.0E-04	0.0	0.22	0.53	1.0	3.1E-07	3.3E-05	0%	N
137	Methylene bis(2-chloroaniline), 4,4'-	101144	2.1E-02	0.1	3.36	8.06	0.9	7.2E-05	7.6E-03	65%	Y
138	Methylene bis(N,N'-dimethyl)aniline, 4,4'-	101611	8.4E-02	0.5	2.83	6.80	1.0	3.0E-04	3.2E-02	270%	Y
**139	Methylene chloride	75092	3.5E-03	0.0	0.32	0.76	1.0	4.2E-06	4.5E-04	4%	N
140	Methylenedianiline, 4,4'-	101779	1.4E-03	0.0	1.37	3.30	1.0	3.4E-06	3.6E-04	3%	N
141	Michler's ketone	90948	2.5E-02	0.2	3.41	8.19	0.9	8.7E-05	9.2E-03	78%	Y
**142	Mustard Gas	505602	4.5E-03	0.0	0.83	2.00	1.0	8.6E-06	9.1E-04	8%	N
143	Naphthalene	91203	4.7E-02	0.2	0.56	1.34	1.0	7.4E-05	7.8E-03	66%	Y
144	2-Naphthol	135193	1.9E-02	0.1	0.69	1.64	1.0	3.3E-05	3.5E-03	30%	Y
145	Naphthylamine, 1-	134327	7.7E-03	0.0	0.68	1.62	1.0	1.3E-05	1.4E-03	12%	Y
146	Naphthylamine, 2-	91598	8.1E-03	0.0	0.68	1.62	1.0	1.4E-05	1.5E-03	13%	Y
147	Nitrilotriacetic acid	139139	1.0E-04	0.0	1.26	3.01	1.0	2.4E-07	2.5E-05	0%	N
148	Nitro-o-anisidine, 5-	99592	2.1E-03	0.0	0.77	1.84	1.0	3.8E-06	4.0E-04	3%	N
149	Nitrobiphenyl, 4-	92933	3.8E-02	0.2	1.40	3.35	1.0	9.5E-05	1.0E-02	86%	Y
* 150	Nitrofen	1836755	1.9E-01	1.2	4.18	16.33	0.9	7.3E-04	7.7E-02	660%	NA
151	Nitrophenol, 2-	88755	4.0E-03	0.0	0.64	1.54	1.0	6.8E-06	7.2E-04	6%	N
152	Nitrophenol, 2-amino-4-	99570	1.7E-03	0.0	0.78	1.87	1.0	3.2E-06	3.4E-04	3%	N
153	3-Nitrophenol	554847	5.5E-03	0.0	0.64	1.54	1.0	9.4E-06	9.9E-04	8%	N
154	4-Nitrophenol	100027	4.8E-03	0.0	0.64	1.54	1.0	8.2E-06	8.6E-04	7%	N
155	Nitrophenol, 4-amino-2-	119346	9.3E-04	0.0	0.78	1.87	1.0	1.7E-06	1.8E-04	2%	N
156	Nitropropane, 2-	79469	8.8E-04	0.0	0.44	1.06	1.0	1.2E-06	1.3E-04	1%	N
157	Nitroso-di-n-butylamine, n-	924163	3.8E-03	0.0	0.82	1.97	1.0	7.3E-06	7.7E-04	7%	N
158	Nitroso-N-ethylurea, n-	759739	4.9E-04	0.0	0.48	1.16	1.0	7.2E-07	7.6E-05	1%	N
159	Nitroso-N-methylurea, n-	684935	3.9E-04	0.0	0.40	0.97	1.0	5.3E-07	5.6E-05	0%	N
160	Nitrosodiethanolamine, n-	1116547	2.5E-05	0.0	0.60	1.44	1.0	4.0E-08	4.3E-06	0%	N
161	Nitrosodiethylamine, n-	55185	1.0E-03	0.0	0.33	0.80	1.0	1.3E-06	1.3E-04	1%	N
162	Nitrosodiphenylamine, p-	156105	2.6E-02	0.1	1.38	3.31	1.0	6.4E-05	6.7E-03	57%	Y
163	Nitrosomethylvinylamine, n-	4549400	5.1E-04	0.0	0.32	0.78	1.0	6.2E-07	6.5E-05	1%	N

EXHIBIT B-3

CALCULATION OF DERMAL ABSORBED DOSE FOR ORGANIC CHEMICALS IN WATER (continued)

	CHEMICAL	CAS No.	K_p (cm/hr)	B	τ (hr)	t* (hr)	FA	DA_{event} (mg/cm^2-event)	DAD (mg/kg-day)	Derm/ Oral (%)	Chem Assess
164	Nitrosomorpholine, n-	59892	1.8E-04	0.0	0.48	1.14	1.0	2.6E-07	2.7E-05	0%	N
165	Nitrosonornicotine, n-	16543558	1.7E-04	0.0	1.05	2.52	1.0	3.6E-07	3.8E-05	0%	N
166	Nitrosopiperidine, n-	100754	2.9E-05	0.0	9.83	23.60	1.0	1.9E-07	2.1E-05	0%	N
167	n-Nonanol	143088	7.8E-02	0.4	0.69	1.65	1.0	1.4E-04	1.4E-02	122%	Y
168	n-Octanol	111875	2.7E-02	0.1	0.57	1.37	1.0	4.4E-05	4.6E-03	39%	Y
169	Parathion	56382	1.3E-02	0.1	4.57	10.97	0.9	5.2E-05	5.5E-03	47%	Y
* 170	PCB-chlorobiphenyl, 4-	2051629	7.5E-01	4.9	4.63	20.27	0.6	2.0E-03	2.2E-01	1844%	NA
* 171	PCB-hexachlorobiphenyl	26601649	4.3E-01	3.2	11.29	47.90	0.5	1.5E-03	1.6E-01	1378%	NA
**172	Pentachloronitrobenzene	82688	4.2E-02	0.3	4.83	11.60	0.9	1.7E-04	1.8E-02	157%	Y
* 173	Pentachlorophenol	87865	3.9E-01	2.5	3.33	13.82	0.9	1.4E-03	1.4E-01	1226%	NA
174	n-Pentanol	71410	5.5E-03	0.0	0.33	0.80	1.0	6.6E-06	7.0E-04	6%	N
175	Pentanone, 4-methyl-2-	108101	2.7E-03	0.0	0.39	0.93	1.0	3.5E-06	3.7E-04	3%	N
* 176	Phenanthrene	85018	1.4E-01	0.7	1.06	4.11	1.0	3.1E-04	3.3E-02	283%	NA
177	Phenol	108952	4.3E-03	0.0	0.36	0.86	1.0	5.5E-06	5.8E-04	5%	N
178	Phenol, 4,6-dinitro-2-methyl-	534521	3.1E-03	0.0	1.38	3.30	1.0	7.7E-06	8.1E-04	7%	N
179	n-Propanol	71238	1.1E-03	0.0	0.23	0.56	1.0	1.1E-06	1.2E-04	1%	N
180	Propiolactone, beta-	57578	3.1E-04	0.0	0.27	0.65	1.0	3.4E-07	3.5E-05	0%	N
181	Propylene oxide	75569	7.7E-04	0.0	0.23	0.54	1.0	8.0E-07	8.5E-05	1%	N
182	Resorcinol	108463	1.3E-03	0.0	0.44	1.06	1.0	1.8E-06	1.9E-04	2%	N
183	Safrole	94597	1.1E-02	0.1	0.87	2.08	1.0	2.2E-05	2.3E-03	20%	Y
184	Styrene	100425	3.7E-02	0.1	0.41	0.98	1.0	5.0E-05	5.3E-03	45%	Y
185	Styrene oxide	96093	3.9E-03	0.0	0.50	1.20	1.0	5.8E-06	6.2E-04	5%	N
* 186	TCDD	1746016	8.1E-01	5.6	6.82	30.09	0.5	2.2E-03	2.4E-01	2003%	NA
**187	Tetrachlorethylene	127184	3.3E-02	0.2	0.91	2.18	1.0	6.7E-05	7.1E-03	60%	Y
**188	Tetrachloroethane, 1,1,2,2-	79345	6.9E-03	0.0	0.93	2.24	1.0	1.4E-05	1.5E-03	13%	Y
189	Thioacetamide	62555	1.8E-03	0.0	0.28	0.67	1.0	2.0E-06	2.1E-04	2%	N
190	Thiodianiline, 4,4'-	139651	2.1E-03	0.0	1.73	4.16	1.0	6.0E-06	6.3E-04	5%	N
191	Thiourea	62566	1.4E-04	0.0	0.28	0.68	1.0	1.5E-07	1.6E-05	0%	N
192	Thymol	89838	3.7E-02	0.2	0.74	1.78	1.0	6.8E-05	7.2E-03	61%	Y
193	Toluene	108883	3.1E-02	0.1	0.35	0.84	1.0	3.9E-05	4.1E-03	35%	Y
194	Toluidine hydrochloride, o-	636215	1.8E-03	0.0	0.68	1.62	1.0	3.1E-06	3.3E-04	3%	N
195	Toluidine, o-	95534	3.0E-03	0.0	0.42	1.02	1.0	4.1E-06	4.3E-04	4%	N
196	Toxaphene	8001352	1.2E-02	0.1	22.40	53.75	0.8	9.5E-05	1.0E-02	85%	Y
197	Trichlorobenzene, 1,2,4-	120821	6.6E-02	0.3	1.11	2.66	1.0	1.5E-04	1.6E-02	133%	Y

EXHIBIT B-3

CALCULATION OF DERMAL ABSORBED DOSE FOR ORGANIC CHEMICALS IN WATER (continued)

	CHEMICAL	CAS No.	K_p (cm/hr)	B	τ (hr)	t* (hr)	FA	DA_{event} (mg/cm^2-event)	DAD (mg/kg-day)	Derm/ Oral (%)	Chem Assess
**198	Trichloroethane, 1,1,1-	71556	1.3E-02	0.1	0.60	1.43	1.0	2.1E-05	2.2E-03	19%	Y
**199	Trichloroethane, 1,1,2-	79005	6.4E-03	0.0	0.60	1.43	1.0	1.0E-05	1.1E-03	9%	N
**200	Trichloroethylene	79016	1.2E-02	0.1	0.58	1.39	1.0	1.9E-05	2.0E-03	17%	Y
**201	Trichlorofluoromethane	75694	1.3E-02	0.1	0.63	1.51	1.0	2.1E-05	2.3E-03	19%	Y
202	2,4,6-Trichlorophenol	88062	3.5E-02	0.2	1.36	3.27	1.0	8.5E-05	9.0E-03	77%	Y
* 203	Tris(2,3-dibromopropyl) phosphate	126727	3.9E-04	0.0	874.39	2098.53	1.0	2.4E-05	2.6E-03	22%	NA
204	Tris(aziridinyl)-para-benzoquinone	68768	1.0E-05	0.0	2.11	5.07	1.0	3.1E-08	3.3E-06	0%	N
* 205	Urea	57136	2.9E-05	0.0	0.23	0.55	1.0	3.0E-08	3.2E-06	0%	NA
**206	Vinyl bromide	593602	4.3E-03	0.0	0.42	1.02	1.0	6.0E-06	6.3E-04	5%	N
**207	Vinyl chloride	75014	5.6E-03	0.0	0.24	0.57	1.0	5.9E-06	6.3E-04	5%	N
* 208	Water	7732185	1.5E-04	0.0	0.13	0.32	1.0	1.3E-07	1.4E-05	0%	NA
209	Xylene, m-	108383	5.3E-02	0.2	0.42	1.01	1.0	7.3E-05	7.7E-03	65%	Y

EXHIBIT B-4

CALCULATION OF DERMAL ABSORBED DOSE FOR INORGANIC CHEMICALS IN WATER

Notes:

The following default exposure conditions are used to calculate exposure to chemicals in water through showering, assuming carcinogenic effects.

Given below are default values from Exhibit 3-2. For site-specific conditions, change default values to site-specific values.

Conc = 1 ppm = 0.001 mg/cm^3 (default value for purpose of illustration)
SA = 18000 cm^2
t_{event} = 0.58 hr/event (35 minutes/event selected to be RME, due to high uncertainty in the value)
EV = 1 event/day
EF = 350 days/yr
ED = 30 years
BW = 70 kg
AT = 25550 days

Default conditions for screening purposes:

Compare Dermal adults (showering for 35 minutes per day) (RME value for showering) to Oral adults drinking 2 liters of water per day

DAD (mg/day) = DA_{event} x SA x EV
Oral Dose (mg/day) = Conc x IR x ABS_{GI}
where:
IR: Ingestion rate of drinking water = 2000 (cm^3/day = L/day x 1000 cm^3/L)
ABS_{GI}: Absorption fraction in GI tract (chemical specific, from Exhibit 4-1)

Condition for screening: "Y" (yes) when dermal exposure exceeds 10% of oral dose value.

Refer to Appendix A for equations to evaluate DA_{event} and DAD.

The spreadsheet (INORG04_01.XLS) also provides the calculation of the ratio of the dermal dose absorbed to the total dose available from a showering scenario, assuming 5 gallons per minute as a flow rate.

All calculations were performed using the Lotus spreadsheet software, except where noted.

EXHIBIT B-4

CALCULATION OF DERMAL ABSORBED DOSE FOR INORGANIC CHEMICALS IN WATER (continued)

	CHEMICAL	K_p (cm/hr)	Source of K_p (exp or default)	DA_{event} (mg/cm^2-event)	DAD (mg/kg-day)	ABS_{GI} (chemical specific)	Derm/ Oral (%)	Chemical to be assessed
1	Antimony	1.0E-03	default	5.8E-07	6.2E-05	15%	3.50%	N
2	Arsenic (arsenite)	1.0E-03	default	5.8E-07	6.2E-05	95%	0.55%	N
3	Barium	1.0E-03	default	5.8E-07	6.2E-05	7%	7.50%	N
4	Beryllium	1.0E-03	default	5.8E-07	6.2E-05	0.7%	75.00%	Y
5	Cadmium	1.0E-03	experimental	5.8E-07	6.2E-05	2.5%	21.00%	Y
6	Cadmium	1.0E-03	experimental	5.8E-07	6.2E-05	5%	10.50%	Y
7	Chromium (III)	1.0E-03	experimental	5.8E-07	6.2E-05	1.3%	40.38%	Y
8	Chromium (VI)	2.0E-03	experimental	1.2E-06	1.2E-04	2.5%	42.00%	Y
9	Copper	1.0E-03	default	5.8E-07	6.2E-05	57%	0.92%	N
10	Cyanate	1.0E-03	default	5.8E-07	6.2E-05	47%	1.12%	N
11	Manganese	1.0E-03	default	5.8E-07	6.2E-05	6%	8.75%	N
12	Mercuric chloride (other soluble salts)	1.0E-03	experimental	5.8E-07	6.2E-05	7%	7.50%	N
13	Insoluble or metallic mercury	1.0E-03	experimental	5.8E-07	6.2E-05	7%	7.50%	N
14	Nickel	2.0E-04	experimental	1.2E-07	1.2E-05	4%	2.63%	N
15	Selenium	1.0E-03	default	5.8E-07	6.2E-05	30%	1.75%	N
16	Silver	6.0E-04	experimental	3.5E-07	3.7E-05	4%	7.88%	N
17	Thallium	1.0E-03	default	5.8E-07	6.2E-05	100%	0.53%	N
18	Vanadium	1.0E-03	default	5.8E-07	6.2E-05	2.6%	20.19%	Y
19	Zinc	6.0E-04	experimental	3.5E-07	3.7E-05	highly variable		

APPENDIX C
SOIL PATHWAY

This appendix describes the methods used to derive the activity specific body-weighted soil adherence factors and is divided into four sections: (1) Background; (2) Body Part-Specific Surface Areas and Activity-Specific Soil Adherence Factors; (3) Overall Weighted Soil Adherence Factors; and (4) soil loading at the hypothetical mono-layer for the Soil Conservation Service standard soil classifications.

Background

Recent data from Kissel et al. [Kissel et al. (1996a), Kissel et al. (1996b), Kissel et al.(1998), and Holmes et al. (1999)] provide evidence to demonstrate that:

- Soil properties influence adherence;
- Soil adherence varies considerably across different parts of the body; and
- Soil adherence varies with activity.

Given these results, the EPA now recommends that an activity which best represents all soils, body parts, and activities be selected (U.S. EPA, 1997a). Body-part-weighted AFs can then be calculated and used in estimating exposure via dermal contact with soil based on assumed exposed body parts. Data on body-part-specific AFs for specific activities are summarized in Exhibit C-2 and were taken from *Exposure Factors Handbook* (U.S. EPA, 1997a), Table 6-12 and from Holmes et al. (1999). The raw data are available electronically at http://depts.washington.edu/jkspage as presented in Exhibit C-2. These body-part-specific adherence data are then combined as a surface weighted average and 95th percentile for each activity using the exposed body parts that are listed for each scenario. The surface area calculations are presented in Exhibit C-1 and the overall values in Exhibit C-3 and Exhibit 3-3.

Body-Part-Specific Surface Areas

The surface area parameter (SA) describes the amount of skin exposed to the contaminated media. The amount of skin exposed depends upon the exposure scenario. Clothing is expected to limit the extent of the exposed surface area in cases of soil contact. All SA estimates used 50th percentile values to correlate with the

EXHIBIT C-1

BODY PART-SPECIFIC SURFACE AREA CALCULATIONS (CHILDREN)

CHILDREN	Fraction of Total SA (unitless)[1]								Total Body SA (m^2 50th %tile)[2]			
Age (y)	Head	Face[3]	Arms	Forearms[4]	Hands	Legs	Lower legs[4]	Feet	Age (y)	Male Child	Female Child	
<1 [5]	0.182	0.0607	0.137	0.0617	0.053	0.206	0.082	0.0654	<1[5]	0.603	0.579	
1<2	0.165	0.0550	0.13	0.0585	0.0568	0.231	0.092	0.0627	1<2[5]	0.603	0.579	
2<3	0.142	0.0473	0.118	0.0531	0.053	0.232	0.093	0.0707	2<3	0.603	0.579	
3<4	0.136	0.0453	0.144	0.0648	0.0607	0.268	0.107	0.0721	3<4	0.664	0.649	
4<5	0.138	0.0460	0.14	0.0630	0.057	0.278	0.111	0.0729	4<5	0.731	0.706	
5<6 [6]	0.131	0.0437	0.131	0.0590	0.0471	0.271	0.108	0.069	5<6[6]	0.793	0.779	
6<7	0.131	0.0437	0.131	0.0590	0.0471	0.271	0.108	0.069	6<7	0.866	0.843	
7<8 [6]	0.12	0.0400	0.123	0.0554	0.053	0.287	0.115	0.0758	7<8[6]	0.936	0.917	
8<9 [6]	0.12	0.0400	0.123	0.0554	0.053	0.287	0.115	0.0758	8<9[6]	1	1	
9<10	0.12	0.0400	0.123	0.0554	0.053	0.287	0.115	0.0758	9<10	1.07	1.06	
10<11 [6]	0.0874	0.0291	0.137	0.0617	0.0539	0.305	0.122	0.0703	10<11[6]	1.18	1.17	
11<12 [6]	0.0874	0.0291	0.137	0.0617	0.0539	0.305	0.122	0.0703	11<12[6]	1.23	1.3	
12<13	0.0874	0.0291	0.137	0.0617	0.0539	0.305	0.122	0.0703	12<13	1.34	1.4	
13<14	0.0997	0.0332	0.121	0.0545	0.0511	0.32	0.128	0.0802	13<14	1.47	1.48	
14<15 [6]	0.0796	0.0265	0.131	0.0590	0.0568	0.336	0.134	0.0693	14<15[6]	1.61	1.55	
15<16 [6]	0.0796	0.0265	0.131	0.0590	0.0568	0.336	0.134	0.0693	15<16[6]	1.7	1.57	
16<17	0.0796	0.0265	0.131	0.0590	0.0568	0.336	0.134	0.0693	16<17	1.76	1.6	Total avg SA for
17<18	0.0758	0.0253	0.175	0.0788	0.0513	0.308	0.123	0.0728	17<18	1.8	1.63	male/female (m^2)
	Fraction of Total SA: Age-Weighted Body Part-Specific Average											
<1 to <6	0.149	0.050	0.133	0.060	0.055	0.248	0.099	0.069	Total SA (<1to<6yr):	0.666	0.645	**0.656**
<7 to <18	0.097	0.032	0.133	0.060	0.053	0.307	0.123	0.072	Total SA (<7to<18yr):	1.330	1.293	**1.312**
	Surface Area by Body Part (cm^2)[7]											
<1 to <6	977	326	874	393	358	1624	650	451				
<7 to <18	1276	425	1749	787	700	4026	1610	949				

1. Taken from *Exposure Factors Handbook* 1997, Table 6-8.
2. Taken from *Exposure Factors Handbook* 1997, Table 6-6 (male) and Table 6-7 (female).
3. Face SA was assumed to be 1/3 of head SA.
4. Assumed forearm-to-arm ratio (0.45) and lowerleg-to-leg ratio (0.4) equivalent to an adult.
5. Due to lack of data for indicated ages, it was assumed that children <1 and 1<2 yr old had the same total SA as children 2<3 yr old.
6. Due to lack of data for indicated ages, it was assumed that body-part-specific fraction of total SA was equal to that of the next oldest age with data.
7. Body-part-weighted SA for children was calculated by multiplying body-part-specific fraction of total SA by total SA (avg. of male and female). Adult body-part SA was taken from 50%tile body-part SA (avg. of Male/Female). All areas reported to two significant digits.
8. Taken from *Exposure Factors Handbook* 1997, Tables 6-2 (male) and 6-3 (female).

EXHIBIT C-1

BODY PART-SPECIFIC SURFACE AREA CALCULATIONS (ADULTS)

ADULT			
	Surface Area of Adults (50th percentile[8]) (cm^2)		
Body Part	Male	Female	Average
Total	19400	16900	18150
Face[3]	433	370	402
Forearms[4]	1310	1035	1173
Hands	990	817	904
Lower legs[4]	2560	2180	2370
Feet	1310	1140	1225

1. Taken from *Exposure Factors Handbook* 1997, Table 6-8.
2. Taken from *Exposure Factors Handbook* 1997, Table 6-6 (male) and Table 6-7 (female).
3. Face SA was assumed to be 1/3 of head SA.
4. Assumed forearm-to-arm ratio (0.45) and lower leg-to-leg ratio (0.4) equivalent to an adult.
5. Due to lack of data for indicated ages, it was assumed that children <1 and 1<2 yr old had the same total SA as children 2<3 yr old.
6. Due to lack of data for indicated ages, it was assumed that body-part-specific fraction of total SA was equal to that of the next oldest age with data.
7. Body-part-weighted SA for children was calculated by multiplying body-part-specific fraction of total SA by total SA (avg. of male and female). Adult body-part SA was taken from 50%tile body-part SA (avg. of Male/Female). All areas are reported to two significant digits.
8. Taken from *Exposure Factors Handbook* 1997, Tables 6-2 (male) and 6-3 (female).

EXHIBIT C-2

ACTIVITY BODY PART-SPECIFIC SOIL ADHERENCE FACTORS

Activity	ID	Age	Gender	Post-activity Loading (mg/cm^2)					Weighted AFs (mg/cm^2)	
				Hands	Arms	Legs	Faces	Feet	Geometric Mean	95th Percentile
Children Playing	CPGPo14		M	0.193	0.015	0.056	0.002	x		
(dry soil)	CPGPo15		M	0.139	0.010	0.022	0.004	x		
	CPGPo16		F	0.021	0.002	0.020	0.002	x		
	CPGPo17		M	0.147	0.018	0.017	0.002	x		
	CPGPo18		F	0.102	0.095	0.336	0.022	x		
			Avg(ln x)	-2.337	-4.305	-3.163	-5.565	x		
			Stdev(ln x)	0.881	1.424	1.250	1.042	x		
			GeoMean	0.097	0.014	0.042	0.004	x		
			1-tailed t-dist. value	2.132	2.132	2.132	2.132	x		
			95th Percentile	0.632	0.281	0.608	0.035	x		
								(face, forearms, hands, lowerlegs)	0.040	0.431
Daycare Children No. 1a	D1a1	6.5	M	0.252	0.027	0.067	x	0.205		
	D1a2	4	M	0.088	0.044	0.015	x	0.087		
	D1a3	2	M	0.208	0.043	0.030	x	0.024		
	D1a4	1.75	M	0.081	0.027	0.023	x	0.110		
	D1a5	1	M	0.114	0.029	0.041	x	0.031		
	D1a6	1	F	0.043	0.008	0.027	x	0.171		
Daycare Children No. 1b	D1b1	6.5	M	0.094	0.018	0.026	x	0.210		
	D1b2	4	M	0.089	0.024	0.019	x	0.117		
	D1b3	2	M	0.505	0.037	0.023	x	0.126		
	D1b4	1.75	M	0.104	0.035	0.027	x	0.111		
	D1b5	1	M	0.263	0.084	0.018	x	0.082		
	D1b6	1	F	0.091	0.017	0.026	x	0.204		
Daycare Children No. 3	D3a	4.5	M	0.031	0.015	0.017	x	0.015		
	D3b	1.5	F	0.026	0.010	0.020	x	0.008		
	D3c	1.3	M	0.040	0.011	0.040	x	0.013		
	D3d	2	M	0.050	0.010	0.003	x	0.000		
			Avg(ln x)	-2.375	-3.791	-3.787	x	-3.015		
			Stdev(ln x)	0.823	0.652	0.652	x	1.630		
			GeoMean	0.093	0.023	0.023	x	0.049		
			1-tailed t-dist. value	1.753	1.753	1.753	x	1.753		
			95th Percentile	0.394	0.071	0.071	x	0.853		
								(forearms, hands, lowerlegs, feet)	0.043	0.324

EXHIBIT C-2

ACTIVITY BODY PART-SPECIFIC SOIL ADHERENCE FACTORS (continued)

Activity	ID	Age	Gender	Post-activity Loading (mg/cm^2)					Weighted AFs (mg/cm^2)	
				Hands	Arms	Legs	Faces	Feet	Geometric Mean	95th Percentile
Children Playing	CPGPo1		M	1.398	0.026	1.320	0.013	x		
(wet soil)	CPGPo2		F	0.290	0.005	0.184	0.010	x		
	CPGPo3		M	0.127	0.009	0.037	0.012	x		
	CPGPo4		M	0.928	0.069	0.669	0.009	x		
	CPGPo5		M	0.036	0.008	0.004	0.005	x		
	CPGPo6		F	0.565	0.011	0.010	0.002	x		
	CPGPo7		F	0.681	0.015	0.131	0.006	x		
	CPGPo8		M	0.163	0.006	0.072	0.004	x		
	CPGPo9		F	4.743	0.101	0.778	0.006	x		
	CPGPo10		M	4.969	0.064	0.001	0.002	x		
	CPGPo11		M	0.274	0.003	0.000	0.001	x		
	CPGPo12		F	1.384	0.005	0.001	0.001	x		
	CPGPo13		M	4.326	0.034	0.002	0.006	x		
			Avg(ln x)	-0.421	-4.185	-3.634	-5.409	x		
			Stdev(ln x)	1.509	1.134	2.732	0.870	x		
			GeoMean	0.656	0.015	0.026	0.004	x		
			1-tailed t-dist. value	1.782	1.782	1.782	1.782	x		
			95th Percentile	9.660	0.115	3.439	0.021	x		
								(face, forearms, hands, lowerlegs)		3.327
Indoor Children No. 1	IK1a	13	F	0.003	0.004	0.004	x	0.011		
	IK1b	11.5	M	0.008	0.003	0.003	x	0.010		
	IK1c	10	M	0.014	0.011	0.011	x	0.020		
	IK1d	6.5	M	0.009	0.002	0.002	x	0.011		
Indoor Children No. 2	IK2a	13	F	0.022	0.005	0.002	x	0.004		
	IK2b	11.5	M	0.011	0.003	0.002	x	0.007		
	IK2c	10	M	0.015	0.010	0.005	x	0.015		
	IK2d	6.5	M	0.010	0.001	0.002	x	0.007		
	IK2e	7	M	0.025	0.004	0.004	x	0.014		
	IK2f	3	F	0.009	0.005	0.004	x	0.015		
Daycare Children No. 2	D2a	4	M	0.042	0.015	0.018	x	0.063		
	D2b	1	F	0.064	0.020	0.012	x	0.056		
	D2c	1	M	0.070	0.020	0.007	x	0.035		
	D2d	2	M	0.070	0.032	0.009	x	0.034		
	D2e	2	M	0.159	0.033	0.011	x	0.041		
			Avg(ln x)	-3.889	-4.912	-5.282	x	-4.089		
			Stdev(ln x)	1.076	0.994	0.743	x	0.823		
			GeoMean	0.020	0.007	0.005	x	0.017		
			1-tailed t-dist. value	1.761	1.761	1.761	x	1.761		
			95th Percentile	0.136	0.042	0.019	x	0.071		
								(forearms, hands, lowerlegs, feet)	0.011	0.059

EXHIBIT C-2

ACTIVITY BODY PART-SPECIFIC SOIL ADHERENCE FACTORS (continued)

Activity	ID	Age	Gender	Post-activity Loading (mg/cm^2)					Weighted AFs (mg/cm^2)	
				Hands	Arms	Legs	Faces	Feet	Geometric Mean	95th Percentile
Children-in-Mud No. 1	K1a	11	M	74.283	5.863	36.130	x	51.528		
	K1b	11	M	42.074	2.672	15.022	x	19.960		
	K1c	10	F	18.669	0.931	18.440	x	36.569		
	K1d	14	M	108.669	58.217	86.589	x	104.444		
	K1e	9	M	13.222	23.164	38.571	x	2.377		
	K1f	9	M	22.203	91.537	68.453	x	20.507		
Children-in-Mud No. 2	K2a	11	M	145.065	54.855	15.457	x	22.738		
	K2b	11	M	99.781	2.353	11.983	x	9.923		
	K2c	10	F	31.991	13.949	2.042	x	0.051		
	K2d	14	M	103.279	46.281	20.643	x	43.810		
	K2e	9	M	16.018	3.568	12.798	x	4.975		
	K2f	9	M	49.127	5.104	7.145	x	35.152		
			Avg(ln x)	3.808	2.386	2.919	x	2.539		
			Stdev(ln x)	0.836	1.515	1.012	x	2.022		
			GeoMean	45.059	10.873	18.525	x	12.663		
			1-tailed t-dist. value	1.796	1.796	1.796	x	1.796		
			95th Percentile	202.293	165.249	113.959	x	478.270		
								(forearms, hands, lowerlegs, feet)	20.601	230.663

EXHIBIT C-2

ACTIVITY BODY PART-SPECIFIC SOIL ADHERENCE FACTORS (continued)

Activity	ID	Age	Gender	Post-activity Loading (mg/cm^2)					Weighted AFs (mg/cm^2)	
				Hands	Arms	Legs	Faces	Feet	Geometric Mean	95th Percentile
Grounds keepers No. 1	G1a	52	M	0.444	0.007	x	0.004	0.024		
	G1b	29	F	0.053	0.004	x	0.001	0.013		
Grounds keepers No. 2	G2a	33	F	0.037	0.001	0.001	0.007	x		
	G2b	34	M	0.195	0.006	0.001	0.018	x		
	G2c	28	M	0.171	0.004	0.002	0.024	x		
	G2d	37	F	0.056	0.001	0.001	0.007	x		
	G2e	22	M	0.133	0.003	0.001	0.005	x		
Grounds keepers No. 3	G3a	43	M	0.026	0.005	0.003	0.009	x		
	G3b	40	F	0.006	0.001	0.000	0.001	x		
	G3c	45	F	0.058	0.002	x	0.003	0.004		
	G3d	30	M	0.029	0.002	0.002	0.013	x		
	G3e	43	M	0.034	0.002	0.001	0.005	x		
	G3f	49	M	0.029	0.003	0.001	0.002	x		
	G3g	62	M	0.086	0.004	0.001	0.010	x		
Grounds keepers No. 4	G4a	38	F	0.067	0.011	0.000	0.002	x		
	G4b	30	M	0.030	0.021	0.001	0.006	x		
	G4c	22	M	0.128	0.027	0.001	0.005	x		
	G4d	34	F	0.050	0.005	0.002	0.002	x		
	G4e	27	F	0.017	0.010	x	0.002	0.018		
	G4f	29	M	0.034	0.012	0.000	0.001	x		
	G4g	35	M	0.053	0.022	0.001	0.003	x		
Grounds keepers No. 5	G5a	44	M	0.052	0.032	0.001	0.006	x		
	G5b	43	M	0.014	0.033	0.001	0.005	x		
	G5c	40	F	0.016	0.018	0.001	0.001	x		
	G5d	64	M	0.033	0.049	0.001	0.006	x		
	G5e	45	F	0.042	0.030	0.001	0.002	x		
	G5f	31	M	0.056	0.045	0.002	0.006	x		
	G5g	49	M	0.033	0.024	0.001	0.004	x		
	G5h	19	M	0.037	0.002	0.001	0.008	x		
			Avg(ln x)	-3.069	-4.983	-6.942	-5.468	-4.388		
			Stdev(ln x)	0.863	1.278	0.565	0.819	0.776		
			GeoMean	0.046	0.007	0.001	0.004	0.012		
			1-tailed t-dist. value	1.701	1.701	1.711	1.701	2.353		
			95th Percentile	0.202	0.060	0.003	0.017	0.077		
Residential Scenario (face, forearms, hands, lowerlegs)									0.011	0.055
Commercial/Industrial (face, forearms, hands)									0.021	0.105

EXHIBIT C-2

ACTIVITY BODY PART-SPECIFIC SOIL ADHERENCE FACTORS (continued)

Activity	ID	Age	Gender	Post-activity Loading (mg/cm^2)					Weighted AFs (mg/cm^2)	
				Hands	Arms	Legs	Faces	Feet	Geometric Mean	95th Percentile
Landscaper/ Rockery	LR1	43	F	0.067	0.034	x	0.010	x		
	LR2	36	M	0.159	0.060	x	0.007	x		
	LR3	27	M	0.091	0.039	x	0.007	x		
	LR4	43	M	0.028	0.010	x	0.002	x		
			Avg(ln x)	-2.630	-3.507	x	-5.168	x		
			Stdev(ln x)	0.730	0.755	x	0.635	x		
			GeoMean	0.072	0.030	x	0.006	x		
			1-tailed t-dist. value	2.353	2.353	x	2.353	x		
			95th Percentile	0.402	0.177	x	0.025	x		
Residential Scenario (face, forearms, hands, lowerlegs)									0.041	0.234
Commercial/Industrial (face, forearms, hands)									0.041	0.234
Gardeners No. 1	GA1a	16	F	0.515	0.055	0.065	0.065	x		
	GA1b	21	F	0.262	0.026	x	0.025	x		
	GA1c	22	F	0.094	0.030	x	0.043	x		
	GA1d	35	F	0.071	0.267	x	0.059	0.066		
	GA1e	22	F	0.177	0.035	x	0.097	x		
	GA1f	27	M	0.310	0.044	0.080	x	0.440		
	GA1g	23	F	0.257	0.033	x	0.060	x		
	GA1h	31	F	0.194	0.070	x	0.088	x		
Gardeners No. 2	GA2a	43	F	0.155	0.048	0.053	0.093	x		
	GA2b	32	M	0.173	0.059	x	x	0.263		
	GA2c	34	M	0.262	0.071	x	0.058	x		
	GA2d	32	F	0.083	0.018	0.013	0.024	x		
	GA2e	33	F	2.057	0.407	x	0.056	x		
	GA2f	52	F	0.116	0.049	0.028	0.031	x		
	GA2g	26	F	0.043	0.017	0.013	0.047	x		
			Avg(ln x)	-1.662	-2.961	-3.411	-2.949	-1.626		
			Stdev(ln x)	0.919	0.872	0.802	0.463	0.983		
			GeoMean	0.190	0.052	0.033	0.052	0.197		
			1-tailed t-dist. value	1.761	1.761	2.015	1.782	2.920		
			95th Percentile	0.958	0.240	0.166	0.119	3.473		
Residential Scenario (face, forearms, hands, lowerlegs)									0.068	0.328
Commercial/Industrial (face, forearms, hands)									0.102	0.482
Irrigation Installers	IR1	41	M	0.281	0.039	0.007	0.006	x		
	IR2	35	M	0.279	0.014	0.004	0.006	x		
	IR3	20	M	0.110	0.003	0.004	0.004	x		
	IR4	23	M	0.132	0.008	0.003	0.008	x		
	IR5	28	M	0.129	0.045	0.015	0.008	x		
	IR6	23	M	0.300	0.062	0.007	0.007	x		
			Avg(ln x)	-1.671	-4.007	-5.214	-5.064	x		
			Stdev(ln x)	0.467	1.170	0.610	0.289	x		
			GeoMean	0.188	0.018	0.005	0.006	x		
			1-tailed t-dist. value	2.015	2.015	2.015	2.015	x		
			95th Percentile	0.482	0.192	0.019	0.011	x		
(face, forearms,hands)									0.078	0.268

EXHIBIT C-2

ACTIVITY BODY PART-SPECIFIC SOIL ADHERENCE FACTORS (continued)

Activity	ID	Age	Gender	Post-activity Loading (mg/cm^2)					Weighted AFs (mg/cm^2)	
				Hands	Arms	Legs	Faces	Feet	Geometric Mean	95th Percentile
Staged Activity:	APDGPo1a		M	0.131	0.003	0.001	0.003	x		
Pipe Layers	APDGPo2a		M	0.243	0.036	0.258	0.006	x		
(dry soil)	APDGPo3a		M	0.216	0.010	0.113	0.020	x		
	APDGPo4a		F	0.158	0.009	0.046	0.003	x		
	APDGPo5a		F	0.106	0.008	0.093	0.003	x		
	APDGPo6a		F	0.174	0.008	0.296	0.003	x		
	APDGPo1b		M	0.182	0.005	0.000	0.001	x		
	APDGPo2b		M	0.125	0.007	0.166	0.007	x		
	APDGPo3b		M	0.133	0.108	0.115	0.004	x		
	APDGPo4b		F	0.397	0.011	0.095	0.004	x		
	APDGPo5b		F	0.124	0.015	0.112	0.008	x		
	APDGPo6b		F	0.075	0.004	0.393	0.007	x		
	APDGPo1c		M	0.551	0.005	0.001	0.002	x		
	APDGPo2c		M	0.311	0.022	0.355	0.006	x		
	APDGPo3c		M	0.184	0.088	0.246	0.004	x		
	APDGPo4c		F	0.226	0.019	0.131	0.006	x		
	APDGPo5c		F	0.168	0.010	0.104	0.012	x		
	APDGPo6c		F	0.133	0.012	0.579	0.008	x		
			Avg(ln x)	-1.721	-4.419	-2.713	-5.354	x		
			Stdev(ln x)	0.484	0.984	2.214	0.663	x		
			GeoMean	0.179	0.012	0.066	0.005	x		
			1-tailed t-dist. value	1.740	1.740	1.740	1.740	x		
			95th Percentile	0.416	0.067	3.122	0.015	x		
								(face, forearms, hands)	0.072	0.186
Construction Workers	CO1	26	M	0.376	0.132	0.066	0.033	x		
	CO2	27	M	0.283	0.044	0.046	0.013	x		
	CO3	24	M	0.230	0.129	0.056	0.045	x		
	CO4	22	M	0.179	0.061	0.052	0.023	x		
	CO5	22	M	0.440	0.128	0.125	0.035	x		
	CO6	30	M	0.141	0.102	0.080	0.026	x		
	CO7	24	M	0.164	0.132	x	0.058	x		
	CO8	21	M	0.266	0.105	0.063	0.021	x		
			Avg(ln x)	-1.418	-2.328	-2.716	-3.550	x		
			Stdev(ln x)	0.401	0.416	0.334	0.478	x		
			GeoMean	0.242	0.098	0.066	0.029	x		
			1-tailed t-dist. value	1.895	1.895	1.943	1.895	x		
			95th Percentile	0.518	0.215	0.127	0.071	x		
								(face, forearms, hands)	0.139	0.302

EXHIBIT C-2

ACTIVITY BODY PART-SPECIFIC SOIL ADHERENCE FACTORS (continued)

Activity	ID	Age	Gender	Post-activity Loading (mg/cm^2)					Weighted AFs (mg/cm^2)	
				Hands	Arms	Legs	Faces	Feet	Geometric Mean	95th Percentile
Heavy Equipment	E1a	54	M	0.115	0.053	x	0.064	x		
Operators No. 1	E1b	34	M	0.281	0.080	x	0.104	x		
	E1c	51	M	0.155	0.091	x	0.152	x		
	E1d	21	M	0.940	0.161	x	0.109	x		
Heavy Equipment	E2a	54	M	0.206	0.192	x	0.146	x		
Operators No. 2	E2b	34	M	0.430	0.339	x	0.194	x		
	E2c	51	M	0.227	0.223	x	0.499	x		
	E2d	21	M	0.500	0.358	x	0.200	x		
			Avg(ln x)	-1.245	-1.867	x	-1.874	x		
			Stdev(ln x)	0.682	0.692	x	0.605	x		
			GeoMean	0.288	0.155	x	0.154	x		
			1-tailed t-dist. value	1.895	1.895	x	1.895	x		
			95th Percentile	1.049	0.573	x	0.483	x		
								(face, forearms, hands)	0.203	0.732
Utility Workers No. 1	U1a	45	M	0.149	0.052	x	0.095	x		
	U1b	27	M	0.243	0.131	x	0.079	x		
	U1c	24	M	0.561	0.184	x	0.084	x		
	U1d	35	M	0.364	0.783	x	0.215	x		
	U1e	24	M	0.437	0.311	x	0.082	x		
Utility Workers No. 2	U2a	23	M	0.269	0.189	x	0.062	x		
	U2b	28	M	0.906	0.835	x	0.197	x		
	U2c	24	M	0.187	0.179	x	0.074	x		
	U2d	34	M	0.109	0.298	x	0.113	x		
	U2e	24	M	0.221	0.219	x	0.092	x		
	U2f	36	M	0.390	0.426	x	0.119	x		
			Avg(ln x)	-1.226	-1.385	x	-2.283	x		
			Stdev(ln x)	0.611	0.793	x	0.393	x		
			GeoMean	0.293	0.250	x	0.102	x		
			1-tailed t-dist. value	1.812	1.812	x	1.812	x		
			95th Percentile	0.889	1.053	x	0.208	x		
								(face,forearms,hands)	0.242	0.856

EXHIBIT C-2

ACTIVITY BODY PART-SPECIFIC SOIL ADHERENCE FACTORS (continued)

Activity	ID	Age	Gender	Post-activity Loading (mg/cm^2)					Weighted AFs (mg/cm^2)	
				Hands	Arms	Legs	Faces	Feet	Geometric Mean	95th Percentile
Staged Activity:	APWGPo1a		M	2.122	0.018	1.410	0.019	x		
Pipe Layers	APWGPo2a		M	19.708	0.999	3.730	0.018	x		
(wet soil)	APWGPo3a		M	10.531	0.030	0.000	0.001	x		
	APWGPo4a		M	0.334	0.005	0.001	0.002	x		
	APWGPo5a		F	0.019	0.001	0.169	0.000	x		
	APWGPo6a		F	0.445	0.013	0.001	0.004	x		
	APWGPo7a		F	0.978	0.003	0.012	0.003	x		
	APWGPo1b		M	4.573	0.113	3.411	0.019	x		
	APWGPo2b		M	14.032	0.446	1.856	0.018	x		
	APWGPo3b		M	3.319	0.001	0.001	0.004	x		
	APWGPo4b		M	1.257	0.018	0.005	0.004	x		
	APWGPo5b		F	4.052	0.013	0.905	0.011	x		
	APWGPo6b		F	1.050	0.018	0.002	0.001	x		
	APWGPo7b		F	1.872	0.004	0.001	0.006	x		
	APWGPo1c		M	1.263	0.370	2.005	0.012	x		
	APWGPo2c		M	7.890	0.439	2.485	0.018	x		
	APWGPo3c		M	6.866	0.147	2.124	0.007	x		
	APWGPo4c		M	0.087	0.002	0.001	0.002	x		
	APWGPo5c		F	6.280	0.085	1.662	0.037	x		
	APWGPo6c		F	0.181	0.010	0.003	0.003	x		
	APWGPo7c		F	3.658	0.029	0.087	0.004	x		
			Avg(ln x)	0.527	-3.741	-3.008	-5.325	x		
			Stdev(ln x)	1.758	2.058	3.607	1.320	x		
			GeoMean	1.694	0.024	0.049	0.005	x		
			1-tailed t-dist. value	1.725	1.725	1.725	1.725	x		
			95th Percentile	35.138	0.826	24.864	0.047	x		
								(face, forearms, hands)	0.630	13.212
Soccer Players No. 1	S1a	13	M	0.068	0.019	0.022	0.012	x		
	S1b	14	M	0.052	0.021	0.251	0.020	x		
	S1c	14	M	0.116	0.005	0.015	0.012	x		
	S1d	15	M	0.120	0.006	0.047	0.011	x		
	S1e	13	M	0.280	0.026	0.092	0.009	x		
	S1f	14	M	0.170	0.004	0.060	0.009	x		
	S1g	13	M	0.146	0.015	0.008	0.020	x		
	S1h	13	M	0.055	0.007	0.005	0.006	x		
			Avg(ln x)	-2.224	-4.555	-3.481	-4.457	x		
			Stdev(ln x)	0.589	0.714	1.322	0.398	x		
			GeoMean	0.108	0.011	0.031	0.012	x		
			1-tailed t-dist. value	1.895	1.895	1.895	1.895	x		
			95th Percentile	0.330	0.041	0.377	0.025	x		
								(face, forearms, hands, lowerlegs)	0.039	0.250

EXHIBIT C-2

ACTIVITY BODY PART-SPECIFIC SOIL ADHERENCE FACTORS (continued)

Activity	ID	Age	Gender	Post-activity Loading (mg/cm^2)					Weighted AFs (mg/cm^2)	
				Hands	Arms	Legs	Faces	Feet	Geometric Mean	95th Percentile
Soccer Players No. 2	S2a	31	F	0.042	0.003	0.004	0.012	x		
	S2b	24	F	0.075	0.003	0.003	0.016	x		
	S2c	34	F	0.063	0.003	0.007	0.011	x		
	S2d	30	F	0.043	0.008	0.033	0.038	x		
	S2e	24	F	0.049	0.021	0.042	0.015	x		
	S2f	25	F	0.055	0.005	0.379	0.020	x		
	S2g	29	F	0.075	0.002	0.007	0.014	x		
	S2h	24	F	0.001	0.002	0.004	0.012	x		
Soccer Players No. 3	S3a	28	F	0.012	0.005	0.010	0.009	x		
	S3b	24	F	0.014	0.002	0.008	0.012	x		
	S3c	30	F	0.039	0.002	0.004	0.014	x		
	S3d	34	F	0.020	0.002	0.010	0.007	x		
	S3e	31	F	0.013	0.013	0.012	0.015	x		
	S3f	28	F	0.026	0.003	0.005	0.008	x		
	S3g	25	F	0.021	0.002	0.013	0.027	x		
			Avg(ln x)	-3.638	-5.632	-4.540	-4.274	x		
			Stdev(ln x)	1.047	0.780	1.253	0.439	x		
			GeoMean	0.026	0.004	0.011	0.014	x		
			1-tailed t-dist. value	1.761	1.761	1.761	1.761	x		
			95th Percentile	0.166	0.014	0.097	0.030	x		
(face, forearms, hands, lowerlegs)									0.012	0.084

EXHIBIT C-2

ACTIVITY BODY PART-SPECIFIC SOIL ADHERENCE FACTORS (continued)

Activity	ID	Age	Gender	Post-activity Loading (mg/cm^2)					Weighted AFs (mg/cm^2)	
				Hands	Arms	Legs	Faces	Feet	Geometric Mean	95th Percentile
Farmers No. 1	F1a	39	F	0.380	0.025	0.002	0.014	x		
	F1b	39	F	0.326	0.020	0.003	0.013	x		
	F1c	44	M	0.794	0.190	0.015	0.025	x		
	F1d	42	M	0.301	0.132	0.012	0.022	x		
Farmers No. 2	F2a	41	F	0.245	0.033	0.033	0.027	x		
	F2b	40	F	0.622	0.175	0.224	0.321	x		
	F2c	43	M	0.571	0.337	0.170	0.045	x		
	F2d	39	M	0.538	0.154	0.008	0.014	x		
	F2e	19	M	0.584	0.142	0.014	0.038	x		
	F2f	18	M	0.407	0.094	0.018	0.022	x		
			Avg(ln x)	-0.802	-2.376	-4.033	-3.524	x		
			Stdev(ln x)	0.374	0.966	1.506	0.932	x		
			GeoMean	0.448	0.093	0.018	0.029	x		
			1-tailed t-dist. value	1.833	1.833	1.833	1.833	x		
			95th Percentile	0.890	0.546	0.280	0.163	x		
								(face, forearms, hands, lowerlegs)	0.117	0.448
Rugby Players No. 1	R1a	22	M	0.207	0.163	0.266	0.072	x		
	R1b	20	M	0.427	0.279	0.695	0.119	x		
	R1c	20	M	1.123	0.451	0.733	0.094	x		
	R1d	20	M	0.338	0.152	0.267	0.008	x		
	R1e	21	M	0.237	0.156	0.237	0.066	x		
	R1f	22	M	0.456	0.418	0.341	0.197	x		
	R1g	22	M	0.413	0.345	0.503	0.032	x		
	R1h	21	M	0.454	0.399	0.189	0.059	x		
Rugby Players No. 2	R2a	33	M	0.147	0.093	0.203	0.066	x		
	R2b	28	M	0.074	0.095	0.064	0.038	x		
	R2c	27	M	0.168	0.141	0.190	0.044	x		
	R2d	26	M	0.139	0.102	0.160	0.055	x		
	R2e	23	M	0.195	0.178	0.140	0.043	x		
	R2f	27	M	0.097	0.058	0.086	0.029	x		
	R2g	27	M	0.164	0.229	0.253	0.070	x		
	R2h	30	M	0.179	0.071	0.173	0.039	x		
Rugby Players No. 3	R3a	27	M	0.052	0.028	0.050	0.021	x		
	R3b	26	M	0.052	0.040	0.083	0.015	x		
	R3c	27	M	0.073	0.023	0.051	0.015	x		
	R3d	27	M	0.043	0.025	0.042	0.022	x		
	R3e	30	M	0.033	0.034	0.060	0.015	x		
	R3f	27	M	0.109	0.042	0.062	0.045	x		
	R3g	24	M	0.023	0.028	0.061	0.020	x		
			Avg(ln x)	-1.919	-2.282	-1.896	-3.244	x		
			Stdev(ln x)	0.968	0.978	0.858	0.773	x		
			GeoMean	0.147	0.102	0.150	0.039	x		
			1-tailed t-dist. value	1.717	1.717	1.717	1.717	x		
			95th Percentile	0.774	0.547	0.655	0.147	x		
								(face, forearms, hands, lowerlegs)	0.129	0.609

EXHIBIT C-2

ACTIVITY BODY PART-SPECIFIC SOIL ADHERENCE FACTORS (continued)

Activity	ID	Age	Gender	Post-activity Loading (mg/cm^2)					Weighted AFs (mg/cm^2)	
				Hands	Arms	Legs	Faces	Feet	Geometric Mean	95th Percentile
Archeologists	AR1	16	F	0.139	0.060	0.031	0.103	0.299		
	AR2	21	F	0.175	0.066	0.021	0.062	x		
	AR3	22	F	0.098	0.019	0.002	0.037	x		
	AR4	35	F	0.158	0.083	0.138	0.102	0.357		
	AR5	22	M	0.201	0.064	0.070	0.047	0.161		
	AR6	27	M	0.114	0.018	0.047	0.030	0.233		
	AR7	23	M	0.138	0.025	0.030	0.023	0.194		
			Avg(ln x)	-1.950	-3.203	-3.567	-2.996	0.249		
			Stdev(ln x)	0.248	0.651	1.400	0.584	0.079		
			GeoMean	0.142	0.041	0.028	0.050	1.283		
			1-tailed t-dist. value	1.943	1.943	1.943	1.943	2.132		
			95th Percentile	0.230	0.144	0.429	0.156	1.518		
								(face, forearms, hands, lowerlegs, feet)	0.302	0.546
Reed Gatherers	RD1	67	F	0.733	0.086	0.333	x	0.844		
	RD2	50	F	0.583	0.017	0.006	x	0.041		
	RD3	42	F	1.392	0.049	0.391	x	1.024		
	RD4	45	F	0.315	0.022	0.820	x	4.492		
			Avg(ln x)	-0.418	-3.336	-1.837	x	-0.457		
			Stdev(ln x)	0.613	0.742	2.215	x	1.965		
			GeoMean	0.658	0.036	0.159	x	0.633		
			1-tailed t-dist. value	2.353	2.353	2.353	x	2.353		
			95th Percentile	2.787	0.204	29.245	x	64.598		
								(forearms, hands, lowerlegs, feet)	0.316	26.662
Tae Kwon Do	TK1	42	M	0.006	0.002	0.002	x3	0.005		
	TK2	8	M	0.013	0.001	0.001	x	0.004		
	TK3	8	M	0.008	0.000	0.003	x	0.004		
	TK4	10	M	0.006	0.011	0.006	x	0.001		
	TK5	11	M	0.011	0.005	0.001	x	0.005		
	TK6	12	M	0.003	0.001	0.001	x	0.002		
	TK7	14	F	0.003	0.005	0.003	x	0.001		
			Avg(ln x)	-5.081	-6.289	-6.230	x	-6.014		
			Stdev(ln x)	0.581	1.301	0.599	x	0.743		
			GeoMean	0.006	0.002	0.002	x	0.002		
			1-tailed t-dist. value	1.943	1.943	1.943	x	1.943		
			95th Percentile	0.019	0.023	0.006	x	0.010		
								(forearms, hands, lowerlegs ,feet)	0.003	0.012

Daycare Children No. 2 from 1997 *Exposure Factors Handbook* (U.S. EPA, 1997), Table 6-11, and Indoor Children Nos 1 & 2 were combined.

average body weights used for all scenarios and pathways. This was done to prevent inconsistent parameter combinations as body weight and SA are dependent variables. Body part-specific SAs were calculated as described under Chapter 3 for adult (>18 years old), teenager (>6 to <18 years old), and child (<1 to <6 years old) receptors and documented in Exhibit C-1.

Weighted Soil Adherence Factors

Given that soil adherence is dependent upon the body part, it is necessary to calculate an overall body part-weighted AF for each activity. The assumed clothing scenario determines which body part-specific AFs are used in calculating the 50th and 95th percentile weighted AFs. The weighted AFs are used in combination with the relative absorption, exposure frequency and duration, exposed surface area, body weight, and averaging time to estimate the dermally absorbed dose. Details on the methods used to calculate the overall weighted AFs are contained under Chapter 3 of the document. The results from the supporting calculations are shown in Exhibit 3-3.

Mono-Layer Soil Loading for USDA Soil Particle Classification

The range of possible soil adherence factors (AF) was calculated using the U.S. Department of Agriculture's (USDA) soil particle size classes expressed in centimeters, the particle density ($P_{particle}$= 2.65 g/cm^3)from the Soil Screening Guidance (U.S. EPA, 1996b), and the Duff and Kissel (1996) equation for a mono-layer, assuming spherical particles and face-centered packing,

$$AF_{monlayer} = [P_{particle} \frac{\frac{\pi d^3}{6}}{d^2}] = P_{particle} \frac{\pi d}{6}$$

These values can be used as bounding estimates as maximums for AF using site-specific soil properties. The AF should not exceed these estimated values based on the mono-layer theory. To restate the recommendation of this guidance, construct the RME exposure scenario with a site-specific upper-end activity pattern, mean AF from Exhibit C-3, and upper-end exposure time. The uncertainty can be bounded by using these maximum estimated mono-layer AF values.

EXHIBIT C-3

OVERALL BODY PART-SPECIFIC WEIGHTED SOIL ADHERENCE FACTORS

		Weighted Soil Adherence Factor (mg/cm^2)	
	Age (years)	**Geometric Mean**	**95th Percentile**
CHILDREN[1]			
Indoor Children	1-13	0.01	0.06
Daycare Children (playing indoors and outdoors)	1-6.5	0.04	0.3
Children Playing (dry soil)	8-12	0.04	0.4
Children Playing (wet soil)	8-12	0.2	3.3
Children-in-Mud[2]	9-14	21	231
RESIDENTIAL ADULTS[3]			
Grounds keepers	>18	0.01	0.06
Landscaper/Rockery	>18	0.04	0.2
Gardeners	>16	0.07	0.3
COMMERCIAL/INDUSTRIAL ADULTS[4]			
Grounds keepers	>18	0.02	0.1
Landscaper/Rockery	>18	0.04	0.2
Staged Activity: Pipe Layers (dry soil)	>15	0.07	0.2
Irrigation Installers	>18	0.08	0.3
Gardeners	>16	0.1	0.5
Construction Workers	>18	0.1	0.3

[1] Weighted AF based on exposure to face, forearms, hands, lower legs, & feet.

[2] Information on soil adherence values for the Children-in-Mud scenario is provided to illustrate the range of values for this type of activity. However, the application of these data to the dermal dose equations in this guidance may result in a significant overestimation of dermal risk. Therefore, it is recommended that the 95 percentile AF values not be used in a quantitative dermal risk assessment. See Exhibit C-4 for bounding estimates.

[3] Weighted AF based on exposure to face, forearms, hands, & lower legs.

[4] Weighted AF based on exposure to face, forearms, & hands.
Note: this results in different weighted AFs for similar activities between residential and commercial/industrial exposure scenarios.

EXHIBIT C-3

OVERALL BODY PART-SPECIFIC WEIGHTED SOIL ADHERENCE FACTORS (continued)

		Weighted Soil Adherence Factor (mg/cm^2)	
	Age (years)	**Geometric Mean**	**95th Percentile**
COMMERCIAL/INDUSTRIAL ADULTS[4] (continued)	>18	0.2	0.7
Utility Workers	>18	0.2	0.9
Staged Activity: Pipe Layers (wet soil)	>15	0.6	13
MISCELLANEOUS ACTIVITIES[5]			
Soccer Players #2 (adults)	>18	0.01	0.08
Soccer Players #1 (teens, moist conditions)	13-15	0.04	0.3
Farmers	>20	0.1	0.4
Rugby Players	>21	0.1	0.6
Archeologists	>19	0.3	0.5
Reed Gatherers	>22	0.3	27

[5] Weighted AF based on all body parts for which data were available

EXHIBIT C-4

ESTIMATION OF SOIL ADHERENCE FACTOR AT MONO-LAYER FOR USDA PARTICLE SIZE SOIL CLASSIFICATIONS

Soil Particle Classification*	Diameter (mm)	AF at mono-layer (mg/cm^2)
Clay, total	<0.002	<0.28
Silt, total	0.002-0.05	0.28-6.9
Silt, fine	0.002-0.02	0.28-2.8
Silt, coarse	0.02-0.05	2.8-6.9
Sand, total	0.05-2.0	6.9-277.5
Very fine sand	0.05-0.1	6.9-13.9
Fine sand	0.1-0.25	13.9-34.7
Medium sand	0.25-0.5	34.7-69.4
Coarse sand	0.5-1.0	69.4-138.8
Very coarse sand	1.0-2.0	138.8-277.5
* USDA 2007. U.S. Department of Agriculture Natural Resources Conservation Service, National Soil Survey Handbook, Particle Size (618.43) http://soils.usda.gov/technical/handbook/contents/part618.html		

APPENDIX D

SAMPLE SCREENING CALCULATIONS

D.1 SAMPLE CANCER SCREENING CALCULATION FOR DERMAL CONTAMINANTS IN WATER

The equations used in calculating the risk from dermal exposure for contaminants in water are summarized in Exhibit D-1. This example illustrates the steps used to calculate the clean-up level from dermal exposure to compounds in water given an acceptable risk of 10^{-6}. The default scenarios used in the calculations are (1) the adult 30 year exposure, and (2) an age-adjusted 30 year exposure incorporating a child bathing for 1 hour/event (RME value), once a day, 350 days/year for 6 years and an adult showering at 35 min/event (RME value), once a day, 350 days/year for 24 years. The general equations are presented for any compound, and the example gives the calculation for one compound in water with a cancer risk of 10^{-6}.

EXHIBIT D-1

SUMMARY OF DERMAL RISK ASSESSMENT PROCESS

Risk Assessment Process		**Cancer Risk**		**Hazard Index**	
Hazard ID		Section 2		Section 2	
Exposure Assessment	**Child or Adult**	**Water Dose**	**Soil Dose**	**Water Dose**	**Soil Dose**
		Section 3.1, Equations 3.1-3.4 Appendix A	Section 3.2, Equations 3.11/3.12	Section 3.1, Equations 3.1-3.4	Section 3.2, Equations 3.11/3.12
	Age-adjusted Child/Adult SFS_{ADJ}	See Note	Section 3.2.2.5 Equation 3.21	See Note	Section 3.2.2.5, Equation 3.21
Toxicity Assessment		Section 4, $SF_{ABS,}$ Equation 4.2		Section 4, RfD_{ABS}, Equation 4.3	
Risk Characterization		Section 5.1, Equation 5.1 DAD x SF_{ABS}		Section 5.1, Equation 5.2 DAD/RfD_{ABS}	
		Uncertainty Analysis Section 5.2			

Note: The calculations used in developing the screening tables in Appendix B (Exhibits B-3 and B-4) for the water pathway determined that the adult receptor experiences the highest dermal dose. Therefore, the adult exposure scenario is recommended for screening purposes. However, if an age-adjusted exposure scenario for the dermal route is selected to be consistent with methods for determining the risk of other routes of exposure (e.g., oral), sample calculations are provided as guidance.

Procedures: Given a cancer risk level at 10^{-6}

1) For cancer risk, from Equation 5.1:

$$DAD = \frac{Dermal\ cancer\ risk}{SF_{ABS}} = \frac{(Dermal\ cancer\ risk)\ x\ (ABS_{GI})}{SF_O} \qquad (D.1)$$

2) For hazard quotient, from Equation 5.2:

$$\begin{aligned} DAD &= Dermal\ hazard\ quotient\ x\ RfD_{ABS} \\ &= Dermal\ hazard\ quotient\ x\ RfD_o\ x\ ABS_{GI} \end{aligned} \qquad (D.2)$$

3) Evaluate DA_{event} from Equation 3.1

$$DA_{event} = \frac{DAD\ x\ BW\ x\ AT}{EV\ x\ ED\ x\ EF\ x\ SA} \qquad (D.3)$$

4) Evaluate permissible water concentration C_w:

For organics, from Equations 3.2 and 3.3:

$$If\ t_{event} \le t^*,\ then:\ C_w = \frac{DA_{event}}{2\ x\ FA\ x\ K_p \sqrt{\frac{6\ \tau_{event}\ x\ t_{event}}{\pi}}} \qquad (D.4)$$

$$If\ t_{event} > t^*,\ then:\ C_w = \frac{DA_{event}}{FA\ x\ K_p \left[\frac{t_{event}}{1 + B} + 2\ \tau_{event} \left(\frac{1 + 3B + 3B^2}{(1 + B)^2} \right) \right]} \qquad (D.5)$$

For inorganics, from Equation 3.4:

$$C_w = \frac{DA_{event}}{K_p\ x\ t_{event}} \qquad (D.6)$$

Parameter	Definition	Default - Child	Default - Adult
TRL	Target Risk Level (unitless)	10^{-6}	10^{-6}
BW	Body Weight (kg)	15	70
AT	Averaging Time (yr)	70	70
SF_{ABS}	Absorbed Cancer Slope Factor $(mg/kg\text{-}day)^{-1}$	chemical-specific	chemical-specific
ED	Exposure Duration (yr)	6	30
EV	Event Frequency (events/day)	1	1
EF	Exposure Frequency (days/yr)	350	350
FA	Fraction Absorbed (unitless)	chemical-specific	chemical-specific
$t_{event\text{-}RME}$	Event Duration (hr)	1 (bathing)	0.58 (showering)
SA	Surface Area (cm^2)	6,600	18,000
K_p	Permeability coefficient (cm/hr)	chemical-specific	chemical-specific
ABS_{GI}	Absorption Fraction (unitless)	chemical-specific	chemical-specific
τ_{event}	Lag time per event (hr)	chemical-specific	chemical-specific
SF_o	Oral Cancer Slope Factor (mg/kg-day)	chemical-specific	chemical-specific
t*	Time to Reach Steady-State (hr)	chemical-specific	chemical-specific
DAD	Dermal Absorbed Dose (mg/kg-day)	site-specific	site-specific
DAD_{event}	Absorbed Dose per Event (mg/cm^2-event)	site-specific	site-specific

Sample Calculations for Exposure to a Carcinogen in Water

Tetrachloroethylene (PCE)

$SF_o = 5.2x10^{-2}$ (mg/kg-d)$^{-1}$

$K_p = 0.033$ cm/hr

$ABS_{GI} = 1$

t* = 2.18 hr

$\tau_{event} = 0.91$ hr

$t_{event} = 0.58$ hr

FA = 1

Residential exposure scenarios

Using Equations D.1, D.3 and D.4 and default values presented:

Adult:

$$DA_{event} = DAD \ x \ AT[\frac{BW_{adult}}{EV_a \ x \ ED_a \ x \ EF_a \ x \ SA_a}] \qquad \text{(D.3)}$$

$$DA_{event} = (1.9\times10^{-5} mg/kg-day)\ (25550 day)[\frac{70kg}{1\ event/day \ x \ 30yr \ x \ 350day/yr \ x \ 18{,}000cm^2}] = 1.8 \ x \ 10^{-7} \ mg/cm^2-event$$

$$C_w = \frac{DA_{event}}{2 \ x \ FA \ x \ K_p \sqrt{\frac{6 \ \tau_{event} \ x \ t_{event}}{\pi}}} \qquad \text{(D.4)}$$

$$C_w = \frac{1.8\times10^{-7} \ mg/cm^2-event}{2 \ (1) \ (0.033 \ cm/hr) \sqrt{\frac{6 \ x \ 0.91 \ hr \ x \ 0.58 \ hr}{\pi}}} = 2.7 \ x \ 10^{-6} mg/cm^3$$

$$C_w = 2.7 \ x \ 10^{-6} mg/cm^3 = 2.7 \ \mu g/L = 2.7 \ ppb$$

Age-Adjusted:

$$DA_{event} = \frac{DAD \times AT}{\frac{EV_c \times ED_c \times EF_c \times SA_c}{BW_{child}} + \frac{EV_a \times ED_a \times EF_a \times SA_a}{BW_{adult}}}$$

Note: age-adjusted t_{event} for 6 years as child and 24 years as adult.

$$t_{event} = \frac{(6\ yr \times 1\ hr/event) + (24\ yr \times 0.58\ hr/event)}{30\ yr}$$

$$t_{event} = 0.66\ hr/event$$

$$DA_{event} = \frac{(1.9 \times 10^{-5} mg/kg-day) \times (25{,}550\ day)}{\frac{(1\ event/day) \times (6\ yr) \times (350\ day/yr) \times (6{,}660\ cm^2)}{15\ kg} + \frac{(1\ event/day) \times (24\ yr) \times (350\ day/yr) \times (18{,}000\ cm^2)}{70\ kg}}$$

$$DA_{event} = 1.6 \times 10^{-7}\ mg/cm^2-event$$

$$C_w = \frac{1.6 \times 10^{-7}\ mg/cm^2-event}{2\ (1)\ (0.033\ cm/hr)\sqrt{\frac{(6) \times (0.91\ hr/event) \times (0.66\ hr/event)}{\pi}}} = 2.3 \times 10^{-6}\ mg/cm^3$$

$$2.3 \times 10^{-6}\ mg/cm^3 = 2.3\ \mu g/L = 2.3\ ppb$$

D.2 SAMPLE NON-CANCER SCREENING CALCULATION FOR CONTAMINANTS IN RESIDENTIAL SOIL

The equations to be used in the determination of a dermal hazard index for residential soil contamination are outlined in Exhibit 5-1. This example uses cadmium in soil and calculates a level of concern that is equal to a hazard index of 1. Following the four steps of the risk assessment process.

Hazard ID: cadmium has both an oral reference dose and ABS_d to allow for a quantitative evaluation.

Exposure Assessment: the scenario to be evaluated is residential soil. Equations 3.11 and 3.12 are combined and solved for the soil concentration C_{soil} resulting in the following.

Example Dermal Calculations Using Child, Adult, and Age-Adjusted Scenarios:

Screening Level Equation for Dermal Contact with <u>Non-Carcinogenic</u> Contaminants in Residential Soil

Equation for use with age-adjusted parameters:

$$C_{soil} = \frac{THQ \ x \ RfD \ x \ BW \ x \ AT \ x \ 365 \ days/yr \ x \ 10^6 \ mg/kg}{ED \ x \ EV \ x \ EF \ x \ SA \ x \ AF \ x \ ABS_d}$$

$$C_{soil} = \frac{THQ \ x \ RfD \ x \ AT \ x \ 365 \ days/yr \ x \ 10^6 \ mg/kg}{EV \ x \ EF \ x \ SFS_{adj} \ x \ ABS_d}$$

Parameter	Definition	Default - Child	Default - Adult	Default - Age-Adjusted
THQ	Target Hazard Quotient (unitless)	1	1	1
BW	Body Weight (kg)	15	70	–

Parameter	Definition	Default - Child	Default - Adult	Default - Age-Adjusted
AT	Averaging Time (yr)	6	30	30
RfD	Reference Dose (mg/kg-day)	chemical-specific	chemical-specific	chemical-specific
ED	Exposure Duration (yr)	6	30	–
EV	Event Frequency (events/day)	1	1	1
EF	Exposure Frequency (days/yr)	350	350	350
SA	Surface Area (cm^2)	2800	5700	–
AF	Adherence Factor (mg/cm^2-event)	0.2	0.07	–
ABS	Absorption Fraction (unitless)	chemical-specific	chemical-specific	chemical-specific
SFS_{adj}	Age-Adjusted Dermal Factor (see equation below)	–	–	360

The age-adjusted, body-part weighted dermal factor is as presented in Section 3.2.2.5.

$$SFS_{adj} = \frac{(SA_{1-6})\ x\ (AF_{1-6})\ x\ (ED_{1-6})}{(BW_{1-6})} + \frac{(SA_{7-31})\ x\ (AF_{7-31})\ x\ (ED_{7-31})}{(BW_{7-31})}$$

$$SFS_{adj} = \frac{(2800cm^2)\ x\ (0.2mg/cm^2-event)\ x\ (6yr)}{(15kg)} + \frac{(5700cm^2)\ x\ (0.07mg/cm^2-event)\ x\ (24yr)}{(70kg)}$$

$$SFS_{adj} = 360\ mg-yrs/kg-event$$

The dermal absorption fraction for cadmium comes from Exhibit 3-4 and is 0.001.

Toxicity Assessment: In order to determine the dermal reference dose, data from Exhibit 4-1 suggests that the gastrointestinal adjustment for cadmium is either 5% for water or, more applicable for this example, 2.5% from food. Therefore, the dermal reference dose is 3E-5 (mg/kg-day) using Equation 4.3, the oral reference dose of 1E-3 from food, and a GI absorption of 2.5%. Note: since the pharmacokinetic model used to derive the oral RfD is based on human data and the differential absorption data between different media is taken into account, the dermal reference dose would be the same via either media, food or water.

$$RfD_{ABS} = RfD_o\ x\ ABS_{GI}$$

$$(1\times10^{-3}mg/kg-day)\ x\ (0.025) = 2.5\times10^{-5}mg/kg-day$$

Risk Characterization: Incorporating all the previous data results in the following:

Sample Calculations for Exposure to a Non-Carcinogen

Cadmium

Child:

$$C_{soil} = \frac{(1)\ x\ (0.000025\ mg/kg\text{-}day)\ x\ (15\ kg)\ x\ (6\ yr)\ x\ (365\ days/yr)\ x\ (10^6\ mg/kg)}{(6\ yr)\ x\ (1\ event/day)\ x\ (350\ days/yr)\ x\ (2800\ cm^2)\ x\ (0.2\ mg/cm^2\text{-}event)\ x\ (0.001)}$$

$$C_{soil} = 700\ mg/kg = 700\ ppm$$

Adult:

$$C_{soil} = \frac{(1)\ x\ (0.000025\ mg/kg\text{-}day)\ x\ (70\ kg)\ x\ (30\ yr)\ x\ (365\ days/yr)\ x\ (10^6 mg/kg)}{(30\ yr)\ x\ (1\ event/day)\ x\ (350\ days/yr)\ x\ (5700\ cm^2)\ x\ (0.07\ mg/cm^2\text{-}event)\ x\ (0.001)}$$

$$C_{soil} = 4{,}600\ mg/kg = 4{,}600\ ppm$$

Age-Adjusted:

$$C_{soil} = \frac{(1)\ x\ (0.000025\ mg/kg\text{-}day)\ x\ (30\ yr)\ x\ (365\ days/yr)\ x\ (10^6 mg/kg)}{(1\ event/day)\ x\ (350\ days/yr)\ x\ (360\ mg\text{-}yr/kg\text{-}event)\ x\ (0.001)}$$

$$C_{soil} = 2{,}200\ mg/kg = 2{,}200\ ppm$$

APPENDIX E

DISCUSSION ON EVALUATING/DEVELOPING SITE-SPECIFIC DERMAL ABSORPTION DATA

In some situations, it may be worthwhile to develop site-specific dermal absorption data during remedial investigations at Superfund sites. Such data would be most useful when dermal exposure contributes significantly to the overall risk and when the default assumptions may not be applicable. In the future, EPA plans to develop detailed laboratory protocols for how to conduct these experiments. To help in the interim, the discussion below offers some general principles and information sources on designing experiments and evaluating the resulting data.

Part E makes numerous references to ORD's 1992 Dermal Exposure Assessment (DEA) and is considered an extension of the principals and methods identified in DEA for Superfund sites. Section 5.1 of the DEA presents a strategy for reviewing data on dermal absorption of chemicals from an aqueous medium. Chapter 6 of the DEA discusses dermal absorption from soils. The literature in this area was and still is quite sparse. Therefore, much less detail is provided on how to evaluate soil data. These portions of the DEA should be reviewed in detail before planning dermal absorption experiments. However, some of the general principles are summarized below:

- Test skin should be healthy and intact.
- Experiments should be conducted in a manner that matches exposure conditions to the extent practical. For water contact scenarios this means using an aqueous vehicle. For soil contact scenarios, this means using a soil load on skin and particle size that matches exposure conditions. Generally, soil loading should not exceed a monolayer. Procedures should be used to ensure that the soil maintains close contact with skin throughout the experiment.
- In vitro tests should use continuous flow and infinite dose procedures.
- In vivo tests should allow periodic collection of data to demonstrate that steady state has been achieved.
- Experiments should be conducted at ambient temperatures, and volatilization should not be prevented.

Other parts or programs of EPA have published guidance on how to conduct dermal absorption studies. While these are generally specific to products rather than contaminated soils or water, they contain some potentially useful information for Superfund assessments and could be consulted for further guidance:

OPPTS Harmonized Test Guidelines. Series 870 Health Effects Test Guidelines–Final Guidelines. 870.7600 Dermal penetration, August 1998,
http://www.epa.gov/opptsfrs/OPPTS_Harmonized/870_Health_Effects_Test_Guidelines/Series/

EPA's Office of Pollution Prevention and Toxic Substances: Federal Register / Vol. 64, No. 110 / page 31074. June 9, 1999. Proposed Test Rule for In Vitro Dermal Absorption Rate Testing of Certain Chemicals of Interest to Occupational Safety and Health Administration.

Similar guidance has also been developed at the international level by the Organization of Economic Cooperation and Development (OECD) and could also be consulted:

OECD (2000a). OECD Guideline for the Testing of Chemicals. Draft Guideline 428: Skin absorption: in vitro method (December 2000).

OECD (2000b). OECD Guideline for the Testing of Chemicals. Draft Guideline 427: Skin absorption: in vivo method (December 2000).

OECD (2000c). Draft guidance document for the conduct of skin absorption studies. OECD environmental Health and Safety Publications Series on Testing and Assessment No. 28 (December 2000).

OECD (2000d) Test Guidelines Program. Percutaneous absorption testing: is there a way to consensus? OECD document ENV/JM/TG(2000)5, April 2000, Paris, France.