PART 201 GENERIC SOIL DIRECT CONTACT CRITERIA
TECHNICAL SUPPORT DOCUMENT

Michigan Department of Environmental Quality
Environmental Response Division

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This technical support document (TSD) presents the methodology for development of the Part 201 generic soil direct contact criteria (DCC) pursuant to Sections 20120a(1)(a),(b), and (d) and 20120(a)(3) of Part 201, Environmental Remediation, of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended. It also provides information about the implementation of the soil DCC. This document replaces the soil DCC TSD dated August 31, 1998.

The soil DCC as represented in this TSD are presented in the Environmental Response Division Operational Memorandum #18: Part 201 Generic Cleanup Criteria Tables, Revision 1 dated June 7, 2000. The Residential and Commercial I DCC are presented in column #19 of the Soil: Residential and Commercial I Table. The Industrial and Commercial II, Commercial III, and Commercial IV DCC are presented in columns #27, #28, and #29, respectively, of the Soil: Industrial and Commercial II, III, and IV Table.

IMPLEMENTATION OF THE DIRECT CONTACT CRITERIA

The soil DCC represent a soil concentration that is protective against adverse health effects due to long-term ingestion of and dermal contact with contaminated soil. DCC which are lower than the target detection limit (TDL) or background, default to the TDL or background. For hazardous substances with criteria greater than their respective soil saturation concentrations (Csat), the criterion defaults to Csat unless a facility-specific demonstration has been made that soils with concentrations greater than Csat do not contain free-phase contaminant. Refer to the Csat TSD (MDEQ, 1998) for details on how this demonstration may be made.

Remedial Action Plans (RAPs) based on soil DCC cannot be approved without a demonstration that all other relevant pathways have been addressed. Since the soil DCC only address long-term ingestion of and dermal contact with contaminated soil, and criteria are not available which address all potential public health or environmental hazards, other concerns may need to be addressed. These types of concerns are noted and discussed in Operational Memorandum #18 (MDEQ, 2000).

Compliance with soil DCC is required throughout the affected medium for generic land use categories, but exposure controls and land use restrictions may be employed to prevent exposures to more highly contaminated soils under the limited land use categories. Facility-specific generic or site-specific DCC may also be developed.

Average on-site soil concentrations, represented as a 95 percent upper confidence level (UCL) on the arithmetic mean, may be used to determine compliance with the soil DCC. On-site 95 percent UCLs should, however, reasonably represent the areas over which exposures are expected to occur. Typically, the exposure area for a residential property is approximately one-quarter acre in size. The distribution of the data (i.e., normal, lognormal or other) must be identified before the 95 percent UCL can be properly calculated. Refer to United States

Environmental Protection Agency (EPA) guidance on how to appropriately calculate the 95 percent UCL (EPA, 1992a). Sample results from hot spots or significantly elevated areas should be addressed separately and not included in the calculation of the 95 percent UCL.

GENERAL INFORMATION ABOUT THE DIRECT CONTACT ALGORITHMS

The equations yield values that represent concentrations of contaminants in soil in units of micrograms per kilogram (ug/kg) or parts per billion (ppb). To convert to units of parts per million or milligrams per kilogram (mg/kg) in soil, divide by 1,000.

The acceptable level of risk for carcinogens is one in one hundred thousand (10^{-5}). Exposure to noncarcinogens is evaluated through the use of a target hazard quotient (THQ). The THQ is the ratio of a single substance's exposure level over a specified time period to a reference dose for that substance derived from a similar exposure period. An acceptable THQ is equal to or less than one. A THQ > 1 indicates an unacceptable exposure (i.e., the exposure level is greater than the reference dose).

Reasonable Maximum Exposure

The EPA provides general guidance on how to characterize exposures and risks when conducting risk assessments. For exposure assessments, intake and exposure values should be selected so that the combination of all variables results in an estimate of the reasonable maximum exposure (RME) for that pathway. The RME is the maximum exposure that is reasonably expected to occur at a site. Under this approach, some intake variables may not be at their individual maximum values, but when in combination with other variables, will result in estimates of the RME (EPA, 1989). EPA guidance (EPA, 1992b), recommends estimating the high-end exposure by "...identifying the most sensitive parameters and using maximum or near-maximum values for one or a few of these variables, leaving others at their mean values." This guidance applies when only limited information on the distribution of the exposure or dose factors is available. This recommendation is based on the fact that maximizing all variables will result in an estimate that is above the range of actual values seen in the population. The algorithms presented in this document follow EPA guidance by combining exposure assumptions which represent a mix of high-end and mid-range values. More specifically, a 70 year life span, body weight and surface area all represent a 50th percentile, while the exposure duration of 21 years and the soil ingestion rate represent 90th percentile values.

Averaging Time

The selection of an appropriate averaging time (AT) is dependent upon the type of toxic effect being evaluated. AT represents the number of days over which the exposure is averaged. When evaluating long-term exposure to noncarcinogenic compounds, exposures are calculated by averaging over the period of exposure (i.e., subchronic or chronic exposures). The approach for developmental toxicants is different. Since one dose of a developmental toxicant can cause adverse effects (particularly during organogenesis), the acceptable daily dose should not be averaged. That is, AT and the exposure parameters [exposure frequency (EF) and exposure duration (ED)] for developmental toxicants should equal 1. For carcinogenic compounds, exposures are calculated by prorating the total cumulative dose over a lifetime (also called lifetime average daily dose). The approach for carcinogens is based on the assumption that a high dose of a carcinogen received over a short period of time is equivalent to a corresponding low dose spread over a lifetime.

Absorption Efficiency

The ingestion absorption efficiency of contaminants is based on the volatility of the chemical, specifically the vapor pressure. Chemicals with a vapor pressure greater than 0.1 millimeters Hg are considered volatile. When chemical-specific data are not available, the default absorption efficiency applicable to ingestion (AE_i) shall be either 100 percent for volatile organic chemicals or 50 percent for other organic chemicals, polychlorinated biphenyls, pesticides, or inorganic parameters.

The default absorption efficiency applicable to dermal contact (AE_d) shall be 10 percent for volatile or semivolatile organic chemicals and 1 percent for inorganic compounds. All generic absorption values represent defaults that may be replaced if chemical-specific data become available (MDEQ, 1999).

Soil Adherence Factor

The soil adherence factor (AF) describes the amount of soil that adheres to the surface of the skin (see Attachment A). The soil AF default values are:

- Residential (Adult) = 0.07 mg/cm^2
- Residential (Child) = 0.2 mg/cm^2

- Commercial III (Adult worker - low soil intensive) = 0.01 mg/cm^2
- Commercial IV (Adult worker - high soil intensive) = 0.1 mg/cm^2

- Industrial (Adult worker) = 0.2 mg/cm^2

Exposure Frequency

The ingestion exposure frequency (EF_i) value for residential exposures to soil/dust is 350 days per year and 245 days per year for commercial/industrial exposures. The residential EF_i of 350 days per year represents the number of days per year that a resident is exposed to soil at their home; it assumes that people spend approximately 15 days per year away from their homes for vacations or other reasons. The EF_i is linked to the soil ingestion rate. The recommended soil ingestion rates account for ingestion of both outdoor soil and indoor dust (EPA, 1991). Constant year round exposure is therefore assumed for the EF_i since there is currently no available method for determining the amount of soil or dust ingested or for determining the effect of climatic conditions on the amount of soil or dust ingested. EPA recommends an EF_i of 250 days/year for industrial /commercial scenarios. An additional 5 days as sick leave or vacation time away from the workplace was used by MDEQ to give an EF_i of 245 days.

The exposure frequency for dermal contact (EF_d) is 245 days per year for the residential scenario and represents outdoor soil exposure. It takes into account EPA's recommendation to consider local weather conditions (e.g. snow cover, frozen soils). It is assumed that Michigan winters last for 4 months (120 days) making soil unavailable for contact. The EF_d for the industrial/commercial scenario is 160 days per year. Allowing three weeks off for vacations and sick leave and adjusting for a standard five day workweek yields a maximum number of 160 days per year for industrial worker outdoor exposure as shown in the calculation below. The assumptions represent high-end values within a range of potential exposures.

$$(365 - 120 - 21) \times 5/7 = 160$$

Exposure Duration
The exposure duration (ED) of 30 years represents the national upper-bound time (90th percentile) at one residence (EPA, 1989).

Ingestion and Dermal Contact Rates
Ingestion and dermal contact rates within the residential soil direct contact algorithm are adjusted to account for differences between children and adults. It is assumed that during the 30 year exposure period, 6 years is spent as a child who ingests more soil per day and the remaining 24 years is spent as a child/adult ingesting less soil per day (EPA, 1991).

For ingestion of soil, EPA guidance (EPA, 1991) recommends a daily intake rate of 200 mg/day for children aged 1-6 years and 100 mg/day for all others. These intake values are believed to represent upper-bound estimates of average soil ingestion rates. EPA recommended soil ingestion rates account for ingestion of both outdoor soils and indoor dust. Data suggest that up to 80 percent of indoor dust consists of outdoor soils that have been brought into a residence by air deposition and foot traffic. Therefore, it cannot be assumed that ingestion of contaminated soil is entirely precluded by climatic conditions such as snow cover. The soil intake values are derived primarily from fecal tracer studies that estimate the amount of soil ingested throughout a day's activities. As such, the intake rates are not event-specific (i.e., the rates do not represent the amount of soil ingested only during outdoor activities).

The soil ingestion rate for industrial/commercial workers is 50 mg/day (EPA, 1991).

Skin Surface Area
The skin surface area (SA) for child and adult receptors in the age-adjusted dermal factor is equal to the 50th percentile values of body part-specific SAs for the respective age group (see Attachment A). Dermal exposure to soil is expected to occur on the head, hands, forearms, and lower legs of an adult and head, hands, forearms, lower legs, and feet of a child.

The SA for industrial/commercial workers is 3,300 cm^2/event. Skin SA is strongly correlated with body weight. Since the assumed body weight represents an average value, SA should be represented by an average value (:) as well. The amount of exposed skin surface area identified below represents a typical scenario, realizing that at times a worker could have more or less skin exposed. For example, there may be times when a worker is working without a shirt and times when a worker may be working in a long-sleeved shirt and/or a coat. The typical scenario assumes that a worker is working in a short-sleeved shirt, long pants, and shoes.

Skin surface area (cm^2) =	: SA head	=	1200
	: SA hands	=	900
	: SA forearms	=	1200
		=	3300

Event Frequency
EPA (1992c; 1997) guidance recommends that default values for soil adherence to skin should be interpreted on an event basis. EPA (1992c; 1998) recommends using an event frequency (EV) parameter with a default value of one event per day for dermal soil exposure risk equations. This is based on the view that soil adherence can occur as the result of a single soil-related activity and soil residence time cannot be adequately predicted due to variability and uncertainty in personal bathing habits. In following with EPA guidance a default value of one event per day is used in the soil DCC equations.

Table 1 provides a summary of the industrial land use category, the commercial land use category and subcategories, as well as the exposure assumptions associated with each category or subcategory. This table may be used to determine the appropriate commercial land use subcategory for a site. Additional information on the commercial land use subcategory can be found in the Generic Commercial Land use Subcategories TSD (MDEQ, 1999).

GENERIC SOIL DIRECT CONTACT ALGORITHMS

Generic Residential and Commercial I Soil DCC:

CARCINOGENS:

$$DCC = \frac{TR \times AT \times CF}{SF \times [(EF_i \times IF \times AE_i) + (EF_d \times DF \times AE_d)]}$$

where,

DCC	(Direct contact criterion)	= ug/Kg (ppb)
TR	(Target risk level)	= 10^{-5}
AT	(Averaging time)	= 25,550 days (70 years x 365 days/year)
CF	(Conversion factor)	= 1E+9 ug/Kg
SF	(Oral cancer slope factor)	= chemical-specific $(mg/Kg\text{-}day)^{-1}$
EF_i	(Ingestion exposure frequency)	= 350 days/year
IF	(Age-adjusted soil ingestion factor)	= 114 mg-year/Kg-day*
AE_i	(Ingestion absorption efficiency)	=chemical-specific or default (see text)
EF_d	(Dermal exposure frequency)	= 245 days/year
DF	(Age-adjusted soil dermal factor)	= 353 mg-year/Kg-day**
AE_d	(Dermal absorption efficiency)	= chemical-specific or default (see text)

NONCARCINOGENS:

$$DCC = \frac{THQ \times RfD \times AT \times CF \times RSC}{[(EF_i \times IF \times AE_i) + (EF_d \times DF \times AE_d)]}$$

where,

DCC	(Direct contact criterion)	= ug/Kg (ppb)
THQ	(Target hazard quotient)	= 1
RfD	(Oral reference dose)	= chemical-specific, mg/Kg-day
AT	(Averaging time)	= 10,950 days (30 years x 365 days/year)
CF	(Conversion factor)	= 1E+9 ug/Kg
RSC	(Relative source contribution)	= 1 or site-specific, if applicable
EF_i	(Ingestion exposure frequency)	= 350 days/year
IF	(Age-adjusted soil ingestion factor)	= 114 mg-year/Kg-day*
AE_i	(Ingestion absorption efficiency)	= chemical-specific or default (see text)
EF_d	(Dermal exposure frequency)	= 245 days/year
DF	(Age-adjusted soil dermal factor)	= 353 mg-year/Kg-day**
AE_d	(Dermal absorption efficiency)	= chemical-specific or default (see text)

$$*IF = \left(\frac{IR_{age1\text{-}6} \times ED_{age1\text{-}6}}{BW_{age1\text{-}6}}\right) + \left(\frac{IR_{adult} \times ED_{adult}}{BW_{adult}}\right)$$

where,

$IR_{age\ 1\text{-}6}$	(Soil ingestion rate)	= 200 mg/day
$ED_{age\ 1\text{-}6}$	(Exposure duration)	= 6 years
$BW_{age\ 1\text{-}6}$	(Body weight)	= 15 Kg
IR_{adult}	(Soil ingestion rate)	= 100 mg/day
ED_{adult}	(Exposure duration)	= 24 years
BW_{adult}	(Body weight)	= 70 Kg

$$**DF = \left(\frac{SA_{age\ 1\text{-}6} \times EV \times AF_{age1\text{-}6} \times ED_{age\ 1\text{-}6}}{BW_{age\ 1\text{-}6}}\right) + \left(\frac{SA_{adult} \times EV \times AF_{adult} \times ED_{adult}}{BW_{adult}}\right)$$

where,

$SA_{age\ 1\text{-}6}$	(Skin surface area)	= 2,670 cm^2/event
EV	(Dermal contact events)	= 1 event/day
$AF_{age\ 1\text{-}6}$	(Soil adherence factor)	= 0.2 mg/cm^2
$ED_{age\ 1\text{-}6}$	(Exposure duration)	= 6 years
$BW_{age\ 1\text{-}6}$	(Body weight)	= 15 Kg
SA_{adult}	(Skin surface area)	= 5,800 cm^2/event
AF_{adult}	(Soil adherence factor)	= 0.07 mg/cm^2
ED_{adult}	(Exposure duration)	= 24 years
BW_{adult}	(Body weight)	= 70 Kg

Generic Industrial and Commercial II Soil DCC:

CARCINOGENS:

$$DCC = \frac{TR \times BW \times AT \times CF}{SF \times ED \times \left[\left(EF_i \times IR_s \times AE_i\right) + \left(EF_d \times SA \times EV \times AF \times AE_d\right)\right]}$$

where,

DCC	(Direct contact criterion)	= ug/Kg (ppb)
TR	(Target risk level)	= 10^{-5}
BW	(Body weight)	= 70 Kg
AT	(Averaging time)	= 25,550 days (70 years x 365 days/year)
CF	(Conversion factor)	= 1E+9 ug/Kg
SF	(Oral cancer slope factor)	= chemical-specific $(mg/Kg\text{-}day)^{-1}$
ED	(Exposure duration)	= 21 years
EF_i	(Ingestion exposure frequency)	= 245 days/year
IR_s	(Soil ingestion rate)	= 50 mg/day

AE_i	(Ingestion absorption efficiency)	= chemical–specific or default (see text)
EF_d	(Dermal exposure frequency)	= 160 days/year
SA	(Skin surface area)	= 3,300 cm^2/event
EV	(Dermal contact events)	= 1 event/day
AF	(Soil adherence factor)	= 0.2 mg/cm^2
AE_d	(Dermal absorption efficiency)	= chemical-specific or default (see text)

NONCARCINOGENS:

$$DCC = \frac{THQ \times RfD \times BW \times AT \times CF \times RSC}{ED \times [(EF_i \times IR_s \times AE_i) + (EF_d \times SA \times EV \times AF \times AE_d)]}$$

where,

DCC	(Direct contact criterion)	= ug/Kg (ppb)
THQ	(Target hazard quotient)	= 1
RfD	(Oral reference dose)	= chemical-specific, mg/Kg-day
BW	(Body weight)	= 70 Kg
AT	(Averaging time)	= 7,665 days (21 years x 365 days/year)
CF	(Conversion factor)	= 1E+9 ug/Kg
RSC	(Relative source contribution)	= 1 (or site-specific if applicable)
ED	(Exposure duration)	= 21 years
EF_i	(Ingestion exposure frequency)	= 245 days/year
IR_s	(Soil ingestion rate)	= 50 mg/day
AE_i	(Ingestion absorption efficiency)	= chemical-specific or default (see text)
EF_d	(Dermal exposure frequency)	= 160 days/year
SA	(Skin surface area)	= 3300 cm^2/event
EV	(Dermal contact events)	= 1 event/day
AF	(Soil adherence factor)	= 0.2 mg/cm^2
AE_d	(Dermal absorption efficiency)	= chemical-specific or default (see text)

Generic Commercial III and IV Soil DCC:

CARCINOGENS:

$$DCC = \frac{TR \times BW \times AT \times CF}{SF \times ED \times [(EF_i \times IR_s \times AE_i) + (EF_d \times SA \times EV \times AF \times AE_d)]}$$

where,

DCC	(Direct contact criterion)	= ug/kg (ppb)
TR	(Target risk level)	= 10^{-5}
BW	(Body weight)	= 70 Kg
AT	(Averaging time)	= 25,550 days (70 years x 365 days/year)
CF	(Conversion factor)	= 1E+9 ug/Kg
SF	(Oral cancer slope factor)	= (chemical-specific mg/Kg-day)$^{-1}$
ED	(Exposure duration)	= 21 years
EF_i	(Ingestion exposure frequency)	= 245 days/year
IR_s	(Soil ingestion rate)	= 50 mg/day

AE_i	(Ingestion absorption efficiency)	= chemical specific or default (see text)
EF_d	(Dermal exposure frequency)	= 160 days/year
SA	(Skin surface area)	= 3,300 cm^2/event
EV	(Dermal contact events)	= 1 event/day
AF	(Soil adherence factor)	= 0.01mg/cm^2 (commercial III) = 0.1 mg/cm^2 (commercial IV)
AE_d	(Dermal absorption efficiency)	= chemical-specific or default (see text)

NONCARCINOGENS:

$$DCC = \frac{THQ \times RfD \times BW \times AT \times CF \times RSC}{ED \times [(EF_i \times IR_s \times AE_i) + (EF_d \times SA \times EV \times AF \times AE_d)]}$$

where,

DCC	(Direct contact criterion)	= ug/Kg (ppb)
THQ	(Target hazard quotient)	= 1
RfD	(Oral reference dose)	= chemical specific (mg/Kg-day)
BW	(Body weight)	= 70 Kg
AT	(Averaging time)	= 7,665 days (21 days x 365 days/year)
CF	(Conversion factor)	= 1E+9 ug/Kg
RSC	(Relative source contribution)	= 1, or site-specific, if applicable
ED	(Exposure duration)	= 21 years
EF_I	(Ingestion exposure frequency)	= 245 days/year
IR_s	(Soil ingestion rate)	= 50 mg/day
AE_I	(Ingestion absorption efficiency)	= chemical-specific or default (see text)
Ef_d	(Dermal exposure frequency)	= 160 days/year
SA	(Skin surface area)	= 3,300 cm^2/event
EV	(Dermal contact events)	= 1 event/day
AF	(Soil adherence factor)	= 0.01 mg/cm^2 (commercial III) = 0.1 mg/cm^2 (commercial IV)
AE_d	(Dermal absorption efficiency)	= chemical-specific or default (see text)

This memorandum is intended to provide guidance to Division staff to foster consistent application of Part 201, Environmental Remediation, of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended, and associated Administrative Rules. This document and matters addressed herein are subject to revision.

Table 1. Summary of the industrial and commercial land use categories, commercial subcategories, and the associated exposure assumptions.

LAND USE CATEGORIES AND SUBCATEGORIES	EXPOSURE ASSUMPTIONS				
	Ingestion Exposure Frequency (days/year)	**Dermal Exposure Frequency (days/year)**	**Exposure Duration (years)**	**Soil Ingestion Rate (mg/day)**	**Skin Surface Area (cm^2/event)**
***Industrial*:** Primary activity is industrial in nature and access to the general public is and will continue to be reliably restricted consistent with its use. Zoning is industrial.	≤245	≤160	≤21	≤50	≤3300
***Commercial*:** Primary activity is commercial in nature. The commercial category is divided into four subcategories to facilitate assessment of potential risk. Zoning is commercial.					
Subcategory I: a property used to house, educate, or provide care for children, the elderly, the infirm, or other sensitive subpopulations (e.g. schools, nursing homes, day cares). Residential cleanup required.	≤350	≤245	≤6 (child) ≤24 (adult)	≤200 (child) ≤100 (adult)	≤2670 (child) ≤5800 (adult)
Subcategory II: activities similar to industrial category. Access to the public is reliably restricted, consistent to its use, by fences, security, or both. Industrial cleanup required.	≤245	≤160	≤21	≤50	≤3300
Subcategory III: Access to the public is unrestricted but less in frequency and duration than workers at the facility (e.g. gas stations, auto dealerships, retail warehouses, auto service stations). The worker population is engaged in activities at the property that are of a low soil intensive nature.	≤245	≤160	≤21	≤50	≤3300
Subcategory IV: Access to the public is unrestricted but less in frequency and duration than workers at the facility (e.g. professional offices, medical/dental offices/clinics, and banks). A groundskeeper worker population has been identified as the appropriate receptor population. The worker population is engaged in activities at the property that are of a high soil intensive nature	≤245	≤160	≤21	≤50	≤3300

REFERENCES

EPA (U.S. Environmental Protection Agency). 1998. Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual, Supplemental Guidance. Dermal Risk Assessment. Interim Guidance. (Peer Consultation Workshop Draft, November 6, 1998) Office of Emergency and Remedial Response.

EPA (U.S. Environmental Protection Agency). 1997. Exposure Factors Handbook. Update to Exposure Factors Handbook, May 1989. Office of Research and Development. EPA/600/P-95/002Fa.

EPA (U.S. Environmental Protection Agency). 1992a. Supplemental Guidance to RAGS: Calculating the Concentration Term. OSWER Publication 9285.7-081. May 1992.

EPA (U.S. Environmental Protection Agency). 1992b. Memorandum: Guidance on Risk Characterization for Risk Managers and Risk Assessors. From: F. Henry Habicht II. February 1992.

EPA (U.S. Environmental Protection Agency). 1992c. Dermal Exposure Assessment: Principles and Applications. Interim Report. EPA/600/8-91/011B. January 1992.

EPA (U.S. Environmental Protection Agency). 1991. Standard Default Exposure Factors. OSWER Directive: 9285.6-03. March 25, 1991.

EPA (U.S. Environmental Protection Agency). 1989. Risk Assessment Guidance for Superfund. Volume I. Human Health Evaluation Manual (Part A). Interim Final. EPA/540/1-89/002. December ,1989.

MDEQ (Michigan Department of Environmental Quality). 2000. Operational Memorandum #18 (Op Memo 18): Part 201 Generic Cleanup Criteria Tables, Revision 1. June 7, 2000.

MDEQ (Michigan Department of Environmental Quality). 1999. Part 201 Generic Commercial Land Use Subcategories: Receptor Populations and Exposure Assumptions for Part 201 Soil Direct Contact Criteria. July 23, 1999.

MDEQ (Michigan Department of Environmental Quality). 1999. Draft Oral and Dermal Absorption Efficiency Technical Support Document. May 18, 1999.

MDEQ (Michigan Department of Environmental Quality). 1998. Generic Soil Saturation Concentrations: Technical Support Document. August 31, 1998.

Attachment A

Soil Dermal Adherence Factor (AF) and Skin Surface Area (SA) Default Values For Part 201 Soil Direct Contact Criteria Technical Support Document

Environmental Response Division
Michigan Department of Environmental Quality

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Soil adherence to the surface of the skin is a parameter in the Part 201 generic soil direct contact criteria (DCC) equations that is used to calculate the dermal (i.e., skin) absorbed dose for a hazardous substance. Specifically, the soil adherence factor (AF) describes the amount of soil that adheres to the surface of the skin. Much of the recent scientific research in this area uses the term "soil loading" to describe soil adherence to skin. The AF in the Part 201 generic soil DCC equations is multiplied by default values for the skin surface area (SA) and dermal absorption efficiency (AE_d) to derive the absorbed dermal dose for a given hazardous substance and land use category. Because soil adherence can vary more than five orders of magnitude depending upon type of activity, soil characteristics and body part, the AF is a sensitive parameter within the portion of the Part 201 soil DCC equations that calculates the dermal absorbed dose.

Recent studies funded by the Environmental Protection Agency (EPA) and reported in the scientific literature have improved the database on soil adherence considerably. The Michigan Department of Environmental Quality (MDEQ) believes this information should be used to update the soil AF default values used in the Part 201 generic soil DCC equations.

BACKGROUND

In 1992, EPA issued guidance indicating a range of AF values from 0.2 to 1.5 mg/cm^2. EPA recommended an AF default value of 0.2 mg/cm^2 as an average and 1.0 mg/cm^2 as a reasonable upper value for all exposed skin (EPA, 1992). Part 201 generic soil DCC for residential and commercial/industrial land use categories were previously calculated using a default AF value of 1.0 mg/cm^2 based on the EPA range of 0.2 to 1.5 mg/cm^2. This EPA range, however, was based on evaluation of a limited number of laboratory (Que Hee et al., 1985; Driver et al., 1989) and field studies (Lepow et al., 1975; Roels et al., 1980). These studies have limited applicability for establishing representative estimates for actual population-wide exposure activities since all of the studies investigated soil adherence to hands only, and used artificial activities to obtain soil adherence measurements that are unlikely to represent typical dermal exposure situations.

The limitations of these studies and other field studies (Lepow et al., 1975; Roels et al., 1980) combined with the frequency of dermal risk estimates exceeding regulatory limits at Superfund sites (Kissel et al., 1996a; Kissel et al., 1996b), precipitated EPA to target soil adherence as a high priority for additional research at a 1993 "Exposure Factors Handbook Workshop" (ERG, 1994). Since this time, additional laboratory studies (Sheppard and Evenden, 1992; Kissel et al., 1996a; Holmes et al., 1996) and direct measurements from a field study of soil loadings have also been published (Kissel et al., 1996b; Holmes et al., 1999).

Field studies provide a more appropriate database for developing soil AF estimates since they report ***direct*** measurements of soil adherence to multiple body parts under actual field conditions (i.e., "unstaged" activities). These data are more likely to represent typical human behaviors as opposed to soil adherence estimates developed under controlled experimental conditions. Collectively, these studies provide good evidence to support the following generalizations concerning soil adherence to skin:

- Adherence varies with type of ***activity***, with the highest levels associated with outdoor workers, followed by outdoor recreational activities and then gardening activities.

- Physical ***soil properties*** such as moisture content, particle size and organic carbon or clay content affect the extent of soil adherence. For example, the highest adherence of soil to skin was associated with contact with wet soils as might occur during wading or other shore area related recreational activities. Adherence decreases with increasing particle size, and is not affected by changes in clay or organic carbon content.

- Soil adherence varies considerably across different ***body parts***. The highest levels correspond with typical contact areas such as the hands, knees and elbows, with the lowest levels found on the face.

RECOMMENDED SOIL ADHERENCE FACTORS

EPA recommends selecting an activity that best represents the exposure scenario of interest (EPA, 1997) for development of default soil AFs. The first step is to identify the type of activity and human receptor(s) most likely to be engaged in the activity for the exposure scenario, or generic land use category. The human receptor categories and corresponding activity groups are presented in Table 1. EPA (1999) has categorized the activities under similar land uses and human receptor groups used by MDEQ to calculate
Part 201 generic soil DCC; residential child, residential adult, and commercial/industrial adult worker, though commercial and industrial land uses are treated as one category. Within each receptor category, activities were ranked according to the 50th percentile weighted AF values from lowest to highest. The 50th percentile, instead of the 95th percentile AF values, were selected because they provide a more stable estimation of the true AF; 50th percentile values are not as affected by outliers as the 95th percentile.

Since soil adherence is dependent on which body parts will contact soil during an activity, an overall ***body part-weighted AF*** is calculated for the selected activity. The clothing scenario common to the activity identifies which body part-specific AFs to use for calculating the 50th and 95th percentile weighted AFs. Skin surface area (SA) default values for the body-parts are based on 50th percentile values taken from the EPA *Exposure Factors Handbook* (EFH) (EPA, 1997). The general equation used to calculate the weighted AF for a given activity is presented below:

$$\text{Weighted AF} = \frac{(AF_1)(SA_1) + (AF_2)(SA_2) + \ldots\ldots + (AF_i)(SA_i)}{SA_1 + SA_2 + \ldots\ldots + SA_i} \qquad (1)$$

where,

AF_i	Soil adherence factor of each body part	= activity/land use-specific (mg/cm^2)
SA_i	Skin surface area of each body part	= (cm^2)

For consistency with other contact rates such as soil ingestion, EPA (1999) recommends a default value that is the high-end of the mean (i.e., 95th percentile). Two approaches were considered for consistency with EPA's recommendation: (1) choose a central tendency (i.e., typical) soil contact activity and its high-end weighted AF (i.e., 95th percentile); or (2) select a high-end soil contact activity and the central tendency weighted AF (i.e., 50th percentile) for that activity.

EPA Superfund has statistically evaluated the soil AF data from the recent field and laboratory studies (Kissel et al., 1996a; Kissel et al., 1996b; Holmes et al., 1996; Holmes et al., 1999), and will be presenting their results and recommendations in a new dermal risk assessment guidance document that will supercede previous EPA (1992) guidance. This document, hereafter referred to as the Superfund Dermal Guidance (SDG), is currently in final draft form (EPA, 1999). Conversations with Mark Johnson, Region V EPA, and member of the Superfund Dermal Workgroup, indicated that no change is expected in the default soil AF values recommended in this document (Johnson, 1999). EPA (1997) has also issued guidance in the EFH on the application of AF data in dermal risk assessments that is consistent with that recommended in the SDG. MDEQ believes that the draft soil AF default values recommended by EPA reflect the best available peer reviewed science, and are unlikely to change significantly if at all in the final document. The following soil AF default values are used for calculating Part 201 generic soil DCC:

- Residential (Adult) = 0.07 mg/cm^2
- Residential (Child) = 0.2 mg/cm^2

- Commercial III (Adult worker - low soil intensive) = 0.01 mg/cm^2
- Commercial IV (Adult worker - high soil intensive) = 0.1 mg/cm^2

- Industrial (Adult worker) = 0.2 mg/cm^2

A brief discussion of the basis for each default soil AF value is presented below.

RESIDENTIAL ADULT SOIL AF

The recommended soil AF default value of 0.07 mg/cm^2 for the residential adult exposure scenario is based on activity-specific and body part-specific adherence data presented in Kissel et al. (1996b) and Holmes et al. (1999). The groundskeeper, landscape/rockery and gardener activity groups in these studies best approximate the variety of activities of an adult resident (Table 1). Given the diversity of activities that an adult resident may engage in, a high-end soil contact activity was selected and a 50th percentile weighted AF was derived. A comparison of the gardener 50th percentile AF values with the other activity groups indicates that the outdoor gardener represents a high-end, soil intensive activity. Activities associated

with this group include weeding, pruning, picking fruit and digging small irrigation trenches. Field measurements for the gardener also represent various types of clothing worn, including long pants, shorts, short sleeve shirts and intermittent use of gloves.

Adult Skin Surface Area

The variability in meteorological conditions in Michigan affects both the frequency of skin contact with soil and the total skin SA that could contact soil. The dermal exposure frequency default value (EF_d = 245 days/year) used in the residential soil DCC equation represents 8 months spanning from spring through the autumn season during which skin contact with soil is most probable. Frozen and/or snow covered ground during the winter season is expected to prevent skin contact for the remaining four months of the year. Two different clothing scenarios are used to characterize the amount of skin SA that could contact soil over the 8-month period based on ambient air temperatures. The 8-month period is split into 5 months of generally warm weather in which persons are typically attired in shorts and short sleeves, and 3 cooler months during which an individual is likely to wear long pants and long sleeves. The associated body parts that may contact soil for the two different time periods and the calculated "time-weighted skin SA" of 5,800 cm^2 is presented in the table below.

Adult Body Parts	
5 months (warm)	3 months (cool)
50% upper legs	
Lower legs	
50% upper arm	
Forearms	
Hands	Hands
Head (no neck)	Head (no neck)
Adult Residential Skin SA = 5,800 cm^2	

Since some studies have indicated that exposure can occur under clothing (Maddy et al. 1983), these clothing scenarios are not overly conservative. The adult skin SA default value was derived by calculating the average of the body part-specific 50th percentile values for males and females greater than 18 years of age. Skin SA data were obtained from Tables 6-2 (adult male) and 6-3 (adult female) of the EFH (EPA, 1997). The increase from the previous default value of 5,000 cm^2 is due to use of body part-specific SAs (i.e., head, hands, forearms etc.), whereas the past approach derived the skin SA default value using the 25th percentile of the "total" body SA. All SA default values are based on 50th percentile values since they are correlated with body weights, which are also based on 50th percentile values.

RESIDENTIAL CHILD SOIL AF

The range of activities evaluated for children was more limited than adults. The available data consists of children ages 1-6.5 playing indoors and outdoors (3.5-4 hours) at a daycare center (Holmes et al., 1999), and children 8-12 years old playing for 20 minutes with an assortment of toys (trucks and figures) and digging tools (a trowel and a scoop) in a preconstructed 8'x8' soil bed containing wet and dry soil (Kissel et al., 1998). Due to the limited number of activity types for children, both approaches: (1) choosing a central tendency (i.e., typical) soil contact activity

and using its high-end weighted AF (i.e., 95th percentile), and (2) selecting a high-end soil contact activity and using the central tendency weighted AF (i.e., 50th percentile) for that activity, were used to derive the default soil AF for children. The recommended weighted AF for a child resident (1-6.5 years old) is 0.2 mg/cm^2. This value is based on the 95th percentile weighted AF for children playing at a daycare center (i.e., a central tendency soil contact activity), and the 50th percentile for children playing in wet soil (i.e., a high-end soil activity) (see Table 1).

Playing at a daycare center is considered a central tendency activity since children played indoors as well as outdoors, soil conditions were not controlled, and clothing was not controlled, such that some wore long pants and long-sleeve shirts. This is a truly realistic scenario in that children 1 to 6 years of age are typically in daycare or at home, and are involved in activities similar to those at a daycare. Selecting a 95th percentile weighted AF for children playing at a daycare center is therefore consistent with EPA's recommendation of a high-end mean for contact rates.

Conversely, the intentional placement of children in wet soil for 20 minutes with similar clothing, and coercing them into soil contact by providing toys and digging tools, reflects a high-end activity. In addition, the children were in direct contact with soil for the full duration of the activity and played in "wet" soil, which is known to have higher soil adherence than dry soil. Therefore, selecting a 50th percentile weighted AF for this activity is also consistent with EPA's recommendation to use a high-end mean for contact rates.

Child Skin Surface Area

Similar to adults, two different clothing scenarios are used for children (ages 0 to 6) to derive a time-weighted skin SA default value for soil contact during the 8-month exposure period. The 8-month period is split into 5 months of warm temperature days in which children are assumed to wear shorts, short sleeve shirts and no shoes. The remaining 3 months consist of cooler temperature days during which children are likely to wear long pants and long sleeve shirts. The body part-specific data for male and female children 0-6 years of age are presented in Table 6-8 of the EFH (EPA, 1997) as a percentage of the total body SA. Total body skin SAs based on 50th percentile values for each age were obtained from Table 6-6 (male) and Table 6-7 (female) of the EFH, and were used to calculate average total skin SA for children. A forearm-to-arm ratio of 0.45 and a lower leg-to-leg ratio of 0.4 based on adult SA data were used to calculate the body part-specific SA fractions shown in the equation below. The corresponding body parts of the children for the two clothing scenarios and the calculated default skin SA value of
2,670 cm^2 is presented in the table below.

Child Body Parts	
5 months (warm)	3 months (cool)
50% upper legs	
Lower legs	
50% upper arm	
Forearms	
Hands	Hands
Head (no neck)	Head (no neck)
Feet	

Child Residential Skin SA = 2,670 cm^2	

AGE-ADJUSTED DERMAL FACTOR

An age-adjusted dermal factor ($DF_{soil}^{age-adjusted}$) is calculated to represent dermal exposure spanning the childhood and adulthood years at one residence for 30 years. This approach accounts for changes in skin SA, body weight and soil adherence over the 30 year period. The soil AF and skin SA defaults for children and adults are combined with their respective assumptions for exposure duration and body weight to calculate the residential $DF_{soil}^{age-adjusted}$ as follows:

$$DF_{soil}^{age-adjusted} = \left(\frac{SA_{1-6} \times AF_{1-6} \times ED_{1-6}}{BW_{1-6}}\right) + \left(\frac{SA_{adult} \times AF_{adult} \times ED_{adult}}{BW_{adult}}\right) \quad (2)$$

$$DF_{soil}^{age-adjusted} = \left(\frac{2{,}670 cm^2 \times 0.2 mg/cm^2 \times 6 yr}{15 kg}\right) + \left(\frac{5{,}800 cm^2 \times 0.07 mg/cm^2 \times 24 yr}{70 kg}\right)$$

$$DF_{soil}^{age-adjusted} = 353\ mg-yr/kg-day$$

COMMERCIAL ADULT WORKER SOIL AFs

Holmes et al. (1999) evaluated a representative range of activities that EPA (1999) has designated as common to both commercial and industrial operations. Seven activity groups are listed in Table 1 under the commercial/industrial category. EPA (1999) recommends a single default soil AF applicable to both commercial and industrial land uses. MDEQ, however, does not consider the equipment operator and the construction and utility worker groups to be representative of "daily/weekly" activities at most commercial properties. Given that Section 20120a(1) identifies commercial and industrial land uses as separate land use categories and that generic criteria for these categories are based on exposure assumptions linked to expected human activity patterns, separate soil AFs were developed.

Activity groups above the dotted line in Table 1 represent human receptor groups likely to contact soil at commercial facilities, while those below the dotted line are representative of human receptor populations at industrial land uses.

The types of activities and uses of commercial properties are extremely varied. Some commercial properties may have uses that resemble residential uses, such as day care centers and schools, while others have operations that are more representative of industrial uses. Still, there is a broad range of commercial uses not adequately characterized by residential or industrial uses in terms of the potential for human direct contact with soil. The receptor populations selected for development of commercial soil DCC should represent individuals or employees whose primary work responsibilities involve soil contact, not necessarily the segment of the worker population that is present at the property for the greatest number of days. Generally, it is expected that workers conducting soil-related activities will have greater exposure to soil contaminants than office workers involved predominantly with indoor activities.

This broad range may be segmented into two groups characterized below:

1. The worker population is engaged in activities at the property that are of a low soil intensive nature – ***Commercial III***. The activities of the worker population for these commercial uses do not cause the worker to directly interact with soil.

2. The worker population is engaged in activities at the property that are of a high soil intensive nature - ***Commercial IV***. The worker activities at these types of commercial facilities cause the worker to routinely and directly interact with soil at the property (e.g., maintenance of the property grounds, such as mowing, landscaping, gardening, irrigation system tasks, etc.).

In general the commercial III and IV subcategories are distinguished by the degree of soil related activities likely to occur at the property according to its use.

Commercial Subcategory III (Low soil intensive)

The worker/receptor population at these commercial facilities is expected to engage in low soil intensive activities. Routine outdoor tasks performed by these workers are unlikely to result in direct interaction/contact with soil. The recommended soil AF for the commercial subcategory III DCC equations is 0.01 mg/cm^2. The lowest 50^{th} percentile AF values among the residential and commercial/industrial activity groups in Table 1 were used to guide development of an upper end estimate for this subcategory since information is not currently available to assess

soil adherence for worker populations whose work responsibilities do not typically result in direct contact with soil. Activity groups from the residential category were included in development of this default AF since the activities conducted at residential and commercial properties are similar (see Table 1). Given that there is a slight difference in 50th percentile values for the groundskeeper activity groups between residential and commercial/industrial, the lowest 50th percentile value, 0.01 mg/cm^2, was selected as the default AF.

The following features characterize a commercial subcategory III property. Access to the public is unrestricted, however, the general public's occupancy of the property is expected to be intermittent and significantly less in frequency and duration relative to the population working at the facility. As a result, the worker-based DCC will be protective of the general public. Although some of the activities of the worker population at a subcategory III commercial property are conducted indoors, a significant component of their work is likely to occur outdoors.

This subcategory could include, but is not limited to, the following uses:

- Retail gas stations
- Auto service stations
- Auto dealerships
- Retail warehouses selling the majority of their merchandise indoors but including some limited storage or stockpiling of materials in an outdoor yard (building supply, retail flower and garden shops not involving on site plant horticulture and excluding open air nurseries, tree farms, and sod farms which would fall into an agricultural land use).
- Repair and service establishments including but not limited to, lawn mower, boat, snowmobile, or small appliance repair shops that have small outdoor yards.
- Small warehouse operations

Some modifications to the exposure assumptions for this subcategory are discussed in later sections of this document.

Commercial Subcategory IV (High soil intensive)

A groundskeeper worker population has been identified as a more appropriate receptor population for development of Part 201 generic commercial subcategory IV soil direct contact criteria (DCC). DCC based on the groundskeeper receptor replace the previous office worker-based DCC since groundskeeper activities at these types of facilities are likely to result in greater exposure to soil than those of office workers.

The worker/receptor population at these commercial facilities is expected to engage in high soil intensive activities. The primary tasks associated with these workers will result in physical interaction of the soil. As a result, the groundskeeper, landscape/rockery, irrigation installer and gardener activity groups collectively represent the types of activities proposed for characterizing the commercial subcategory IV.

The recommended soil AF for the commercial subcategory IV DCC equation is 0.1 mg/cm^2, which is the 50th percentile value for the gardener activity group (Table 1). The gardener represents a high-end activity relative to the other activity groups, groundskeeper, landscape/rockery, and irrigation installer, common to commercial land use. Consistent with EPA recommendation, a high-end soil contact activity and a 50th percentile value was chosen

for the commercial default soil AF. This approach is favored over determining which activity group is representative of average soil contact activities, and then selecting a 95th percentile value as the soil AF default. Identifying an average commercial soil contact activity is not feasible given the wide range of activities associated with commercial properties. Selecting a central tendency weighted AF of a high-end soil activity is consistent with recommending a high-end mean for soil contact rates.

The following features characterize a commercial subcategory IV property. Public access to the property is not restricted, however, the general public's occupancy of the facility is intermittent in frequency and of short duration relative to the groundskeeper worker receptor that is resident at the facility (i.e., the frequency and duration of general public occupancy at the property is typified by the time necessary to transact business at a retail establishment or to receive personal services). Since the general public's contact with soil is anticipated to be significantly less than a groundskeeper worker's contact, both in terms of frequency and duration, generic soil DCC are based on the groundskeeper (although the groundskeeper worker is represented by the gardener activity group in Table 1 as noted above). The predominant activities performed by the groundskeeper workers at this type of commercial property are outdoors.

This subcategory could include, but is not limited to, the following uses:

- Professional offices (lawyers, architects, engineers, real estate, insurance, etc.)
- Medical/dental offices and clinics (not including hospitals)
- Banks, credit unions, savings and loan institutions, etc.
- Publicly owned office buildings
- Any retail business whose principal activity is the sale of food or merchandise within an enclosed building
- Personal service establishments which perform services indoors (health clubs, barber/beauty salons, mortuaries, photographic studios, etc.).

Adult Worker Skin Surface Area

The adult commercial receptor is assumed to wear a short-sleeve shirt, long pants, and shoes. The exposed skin SA is therefore limited to the head, hands and forearms, yielding a total skin SA of 3,300 cm^2.

INDUSTRIAL ADULT WORKER SOIL AFs

The equipment operator and construction and utility worker activity groups in Table 1 represent the adult industrial worker receptor. There is little variability in the 50th percentile values among these three groups since these receptors are all engaged in soil intensive activities. Nonetheless, the utility worker group represents a high-end soil activity and contained the larger sample population of the three groups in this category. As a result, the 50th percentile value of 0.2 mg/cm^2 from the utility worker group is the recommended default soil AF for calculation of the generic industrial soil DCC. This value also compares well with the 95th percentile value of 0.3 mg/cm^2 for the construction worker activity group.

Adult Worker Skin Surface Area

The adult industrial receptor is assumed to wear a short-sleeve shirt, long pants, and shoes. The exposed skin SA is therefore limited to the head, hands and forearms, yielding a total skin SA of 3,300 cm^2.

SOIL RESIDENCE/EVENT TIME

Soil residence times refer to the amount of time that soil residues are on the skin. Ideally, a default value for this time period could be used in the DCC equations to account for the number of hours in the day (i.e., exposure time) that soil is considered to be on skin and available for absorption. EPA (1997) guidance indicates that residence time of soil on skin has not been studied, but would likely correspond to the time period between washings, about 8 to 24 hours (EPA, 1992). Since personal hygiene/washing is behavioral dependent, and household dust can have contaminant levels equal to those found outdoors (EPA, 1988), residence or exposure time is assumed as 24 hours/day. Since this is equivalent to a full day of exposure, which is represented by the exposure frequency term, it is not necessary to include exposure time in the soil DCC equations.

This document is intended to provide guidance to ERD staff to foster consistent application of Part 201 of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended, and associated Administrative Rules. This document and matters addressed herein are subject to revision.

TABLE 1

Activity Specific and Skin Surface Area Weighted Soil Adherence Factors

	Age (yr)	Weighted AF (mg/cm^2) 50th %	95th%
CHILDREN[1]			
Children Playing (dry soil)	8 - 12	0.04	0.2
Daycare Kids	1 - 6.5	0.06	0.2
Children Playing (wet soil)	8 - 12	0.2	2.7
RESIDENTIAL ADULTS[2]			
Groundskeepers	>18	0.01	0.5
Landscape/Rockery	>18	0.04	0.1
Gardeners	>16	0.07	0.3
COMMERCIAL/INDUSTRIAL ADULTS[3]			
Groundskeepers	>18	0.02	0.7
Landscape/Rockery	>18	0.04	0.1
Irrigation Installers	>18	0.08	0.2
Gardeners	>16	0.1	0.4
Construction Workers	>18	0.1	0.3
Equip. Operators	>18	0.2	0.6
Utility Workers	>18	0.2	0.8
OTHER RECEPTORS[4]			
Soccer No. 1 (teens: moist conditions)	13 - 15	0.04	0.2
Soccer Nos. 2&3 (adults)	>18	0.01	0.07
Archeologists	>16	0.09	0.3
Farmers	>18	0.1	0.4
Rugby	>18	0.1	0.6

[1] Weighted AF based on exposure to head, forearms, hands, lowerlegs, and feet.

[2] Weighted AF based on exposure to head, forearms, hands, and lowerlegs.

[3] Weighted AF based on exposure to head, forearms, and hands.

Note: This results in different weighted AF's for similar activities between residential and commercial/industrial exposure scenarios.

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

Note: The dashed line under the "COMMERCIAL/INDUSTRIAL ADULTS" heading indicates that activities above the line are likely to occur at commercial land uses; activities likely to occur at industrial land uses are below the dashed line.

(Source: Risk Assessment Guidance For Superfund Volume I: Human Health Evaluation Manual. Supplemental Guidance. Dermal Risk Assessment. 1999. Modified for Part 201 application.)

REFERENCES

Driver, J.H., Konz, J.J., and Whitmyre, G.K. 1989. Soil adherence to human skin. Bull. Environ. Contam. Toxicol. 43:814-820.

EPA (U.S. Environmental Protection Agency). 1988. Estimating exposure to 2,3,7,8-TCDD. Office of Health and Environmental Assessment. Washington D.C. EPA/600/6-88/00SA.

EPA (U.S. Environmental Protection Agency). 1992. Dermal Exposure Assessment: Principles and Applications. Interim Report. Office of Research and Development. EPA/600/8-91/011B.

EPA (U.S. Environmental Protection Agency). 1997. Exposure Factors Handbook. Update to Exposure Factors Handbook, May 1989. Office of Research and Development. EPA/600/P-95/002Fa

EPA (U.S. Environmental Protection Agency). 1999. Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual. (Part E, Supplemental Guidance for Dermal Risk Assessment). Interim Guidance. Office of Emergency and Remedial Response. Final Draft. May 1999.

ERG (Eastern Research Group). 1994. Report on the Exposure Factors Handbook Workshop. EPA Contract No. 68-D9-0013 (June 1994).

Holmes, K.K., Kissel, J.C., and Richter, K.Y. 1996. Investigation of the influence of oil on soil adherence to skin. J. Soil Contam. 5(4):301-308.

Holmes, K.K., Shirai, J.H., Richter, K.Y., and Kissel, J.C. 1999. Field measurements of dermal soil loadings in occupational and recreational activities. Environ. Res. 80(2)(pt1): 148-157.

Johnson, M. 1999. Personal communications with Dr. Mark Johnson, EPA Region V.

Kissel, J.C. 1995. Characterization of soil adherence to skin: impact of historical misinterpretation of the Que Hee et al. Data. Risk Anal. 15(6): 613-614.

Kissel, J.C., Richter, K.Y., and Fenske, R.A. 1996a. Factors affecting soil adherence to skin in hand-press trials. Bull. Environ. Contam. Toxicol. 56:722-728.

Kissel, J.C., Richter, K.Y., and Fenske, R.A. 1996b. Field measurements of dermal soil loading attributable to various activities: Implications for exposure assessment. Risk Anal. 16(1):116-125.

Kissel, J.C., Shirai, J.H., Richter, K.Y., and Fenske, R.A. 1998. Investigation of dermal contact with soil in controlled trials. J. Soil Contam. 7(6):737-752.

REFERENCES (Continued)

Lepow, M.L., Bruckman, L., Gillette, M., Markowitz, S., Rubino, R., and Kapish, J. 1975. Investigations into sources of lead in the environment of urban children. Environ. Res. 10:415-426.

Que Hee, S.S., Peace, B., Clark, C.S., Boyle, J.R., Bornschein, R.L., andHammond, P.B. 1985. Evolution of efficient methods to sample lead sources, such as house dust and hand dust, in the homes of children. Environ. Res. 38:77-95.

Roels, H.A., Buchet, J.P., Lauwenys, R.R., Branx, P., Claeys-Thoreau, F., Lafontaine, A., and Verduyn, G. 1980. Exposure to lead by oral and pulmonary routes of children living in the vicinity of a primary lead smelter. Environ. Res. 22:81-94.

Sheppard, S.C., and Evenden, W.G. 1992. Concentration enrichment of sparingly soluble contaminants (U, Th, and Pb) by erosion and by soil adhesion to plants and skin. Environ. Geochem. Health 14(4):121-132.