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Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities

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Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities

Volume Three
Appendices B and C

APPENDIX B

ESTIMATING MEDIA CONCENTRATION EQUATIONS AND VARIABLE VALUES

Human Health Risk Assessment Protocol

July 1998

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CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS

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γ	=	Empirical constant (unitless)
λ_z	=	Dimensionless viscous sublayer thickness (unitless)
μ_a	=	Viscosity of air (g/cm-s)
μ_w	=	Viscosity of water corresponding to water temperature (g/cm-s)
ρ_a	=	Density of air (g/cm^3 or g/m^3)
ρ_w	=	Density of water corresponding to water temperature (g/cm^3)
θ	=	Temperature correction factor (unitless)
θ_{bs}	=	Bed sediment porosity (L volume/L sediment)—unitless
θ_{sw}	=	Soil volumetric water content (mL water/cm^3 soil)
a	=	Empirical intercept coefficient (unitless)
A	=	Surface area of contaminated area (m^2)
A_{beef}	=	Concentration of COPC in beef (mg COPC/kg FW tissue)
$A_{chicken}$	=	Concentration of COPC in chicken meat (mg COPC/kg FW tissue)
A_{egg}	=	Concentration of COPC in eggs (mg COPC/kg FW tissue)
Ah	=	Area planted (m^2)
Ah_i	=	Area planted to *i*th crop (m^2).
A_I	=	Impervious watershed area receiving COPC deposition (m^2)
A_L	=	Total watershed area receiving COPC deposition (m^2)
A_{milk}	=	Concentration of COPC in milk (mg COPC/kg FW tissue)
A_{pork}	=	Concentration of COPC in pork (mg COPC/kg FW tissue)
A_W	=	Water body surface area (m^2)
b	=	Empirical slope coefficient (unitless)
Ba_{beef}	=	Biotransfer factor for beef (day/kg FW tissue)
$Ba_{chicken}$	=	Biotransfer factor for chicken (day/kg FW tissue)
Ba_{eggs}	=	Biotransfer factor for chicken eggs (day/kg FW tissue)
BAF_{fish}	=	Bioaccumulation factor for COPC in fish (L/kg FW tissue)
Ba_{milk}	=	Biotransfer factor for milk (day/kg FW tissue)
Ba_{pork}	=	Biotransfer factor for pork (day/kg FW tissue)
$BCF_{chicken}$	=	Bioconcentration factor for COPC in chicken (mg COPC/kg FW tissue)/(mg COPC/kg feed)—unitless
BCF_{egg}	=	Bioconcentration factor for COPC in eggs (mg COPC/kg FW tissue)/(mg COPC/kg feed)—unitless
BCF_{fish}	=	Bioconcentration factor for COPC in fish (mg COPC/kg FW tissue)/(mg COPC/kg dissolved water)—unitless
BD	=	Soil bulk density (g soil/cm^3 soil)
Br_{ag}	=	Plant-soil bioconcentration factor for aboveground produce (mg COPC/kg DW plant)/(mg COPC/kg soil)—unitless
$Br_{forage/silage/grain}$	=	Plant-soil bioconcentration factor for forage, silage, and grain (mg COPC/kg DW plB-vant)/(mg COPC/kg soil)—unitless
$Br_{rootveg}$	=	Plant-soil bioconcentration factor for belowground produce (mg COPC/kg DW plant)/(mB-vg COPC/kg soil)—unitless
Bs	=	Soil bioavailability factor (unitless)

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$BSAF$	=	Biota-sediment accumulation factor (mg COPC/kg lipid tissue)/(mg COPC/kg sediment)—unitless
Bv_{ag}	=	COPC air-to-plant biotransfer factor for aboveground produce (mg COPC/kg DW plant)/(mg COPC/kg air)—unitless
Bv_{forage}	=	Air-to-plant biotransfer factor for COPC in forage (mg COPC/kg DW plant)/(mg COPC/kg air)—unitless
c	=	Junge constant = 1.7×10^{-4} (atm-cm)
C	=	USLE cover management factor (unitless)
C_a	=	Air concentration (μg/m^3)
C_{acute}	=	Acute air concentration (μg/m^3)
C_{BS}	=	Bed sediment concentration (or bed sediment bulk density) (g/cm^3 or kg/L)
C_d	=	Drag coefficient (unitless)
C_{dw}	=	Dissolved phase water concentration (mg COPC/L water)
C_{fish}	=	Concentration of COPC in fish (mg COPC/kg FW tissue)
C_{hp}	=	Unitized hourly air concentration from vapor phase (μg-s/g-m^3)
C_{hv}	=	Unitized hourly air concentration from particle phase (μg-s/g-m^3)
Cs	=	Average soil concentration over exposure duration (mg COPC/kg soil)
C_{sb}	=	Concentration sorbed to bed sediment (mg COPC/kg sediment)
Cs_{tD}	=	Soil concentration at time tD (mg COPC/kg soil)
C_{wctot}	=	Total COPC concentration in water column (mg COPC/L water column)
C_{wtot}	=	Total water body COPC concentration including water column and bed sediment (g COPC/m^3 water body) or (mg/L)
Cyp	=	Unitized yearly average air concentration from particle phase (μg-s/g-m^3)
Cyv	=	Unitized yearly average air concentration from vapor phase (μg-s/g-m^3)
$Cywv$	=	Unitized yearly (water body or watershed) average air concentration from vapor phase (μg-s/g-m^3)
D_a	=	Diffusivity of COPC in air (cm^2/s)
d_{bs}	=	Depth of upper benthic sediment layer (m)
Ds	=	Deposition term (mg COPC/kg soil-yr)
d_{wc}	=	Depth of water column (m)
D_w	=	Diffusivity of COPC in water (cm^2/s)
$Dydp$	=	Unitized yearly average dry deposition from particle phase (s/m^2-yr)
$Dytwp$	=	Unitized yearly (water body or watershed) average total (wet and dry) deposition from particle phase (s/m^2-yr)
$Dywp$	=	Unitized yearly average wet deposition from particle phase (s/m^2-yr)
$Dywv$	=	Unitized yearly average wet deposition from vapor phase (s/m^2-yr)
$Dywwv$	=	Unitized yearly (water body or watershed) average wet deposition from vapor phase (s/m^2-yr)
d_z	=	Total water body depth (m)
ER	=	Soil enrichment ratio (unitless)
E_v	=	Average annual evapotranspiration (cm/yr)

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f_{bs} = Fraction of total water body COPC concentration in benthic sediment (unitless)
Fd = Fraction of diet that is soil (unitless)
F_i = Fraction of plant type *i* grown on contaminated soil and ingested by the animal (unitless)
f_{lipid} = Fish lipid content (unitless)
Fw = Fraction of COPC wet deposition that adheres to plant surfaces (unitless)
f_{wc} = Fraction of total water body COPC concentration in the water column (unitless)
F_v = Fraction of COPC air concentration in vapor phase (unitless)

H = Henry's Law constant (atm-m^3/mol)

I = Average annual irrigation (cm/yr)

k = Von Karman's constant (unitless)
K = USLE erodibility factor (ton/acre)
k_b = Benthic burial rate constant (yr^{-1})
Kd_{bs} = Bed sediment/sediment pore water partition coefficient (cm^3 water/g bottom sediment or L water/kg bottom sediment)
Kd_s = Soil-water partition coefficient (cm^3 water/g soil)
Kd_{sw} = Suspended sediment-surface water partition coefficient (L water/kg suspended sediment)
K_G = Gas phase transfer coefficient (m/yr)
K_L = Liquid phase transfer coefficient (m/yr)
K_{oc} = Soil organic carbon-water partition coefficient (mL water/g soil)
K_{ow} = Octanol-water partition coefficient (mg COPC/L octanol)/(mg COPC/L octanol)—unitless
kp = Plant surface loss coefficient (yr^{-1})
ks = COPC soil loss constant due to all processes (yr^{-1})
kse = COPC loss constant due to soil erosion (yr^{-1})
ksg = COPC loss constant due to biotic and abiotic degradation (yr^{-1})
ksl = COPC loss constant due to leaching (yr^{-1})
ksr = COPC loss constant due to surface runoff (yr^{-1})
ksv = COPC loss constant due to volatilization (yr^{-1})
k_v = Water column volatilization rate constant (yr^{-1})
K_v = Overall COPC transfer rate coefficient (m/yr)
k_{wt} = Overall total water body dissipation rate constant (yr^{-1})

L_{DEP} = Total (wet and dry) particle phase and wet vapor phase COPC direct deposition load to water body (g/yr)
L_{Dif} = Vapor phase COPC diffusion (dry deposition) load to water body (g/yr)
L_E = Soil erosion load (g/yr)
L_R = Runoff load from pervious surfaces (g/yr)
L_{RI} = Runoff load from impervious surfaces (g/yr)

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L_T = Total COPC load to the water body (including deposition, runoff, and erosion) (g/yr)
LS = USLE length-slope factor (unitless)

M_{skin} = Mass of a thin (skin) layer of belowground vegetable (g)
$M_{vegetable}$ = Mass of the entire vegetable (g)
MF = Metabolism factor (unitless)

OC_{sed} = Fraction of organic carbon in bottom sediment (unitless)

$p°_L$ = Liquid phase vapor pressure of chemical (atm)
$p°_S$ = Solid phase vapor pressure of chemical (atm)
P = Average annual precipitation (cm/yr)
PF = USLE supporting practice factor (unitless)
Pd = Concentration of COPC in aboveground produce due to direct deposition (mg COPC/kg DW)
P_i = Concentration of COPC in plant type *i* ingested by the animal (mg/kg DW)
Pr_{ag} = Concentration of COPC in aboveground produce due to root uptake (mg COPC/kg DW)
Pr_{bg} = Concentration of COPC in belowground produce due to root uptake (mg COPC/kg DW)
Pv = Concentration of COPC in aboveground produce (forage and silage) due to air-to-plant transfer (µg COPC/g DW plant tissue or mg COPC/kg DW plant tissue)

Q = COPC emission rate (g/s)
Qp_i = Quantity of plant type *i* ingested by the animal (kg DW plant/day)
Qs = Quantity of soil ingested by the animal (kg/day)

r = Interception fraction—the fraction of material in rain intercepted by vegetation and initially retained (unitless)
R = Universal gas constant (atm-m^3/mol-K)
RCF = Root concentration factor (µg COPC/g DW plant)/(µg COPC/mL soil water)
RO = Average annual surface runoff from pervious areas (cm/yr)
RF = USLE rainfall (or erosivity) factor (yr^{-1})
Rp = Interception fraction of the edible portion of plant (unitless)

SD = Sediment delivery ratio (unitless)
ΔSf = Entropy of fusion [$\Delta S_f/R = 6.79$ (unitless)]
SF = Slope factor $(mg/kg\text{-}day)^{-1}$
S_T = Whitby's average surface area of particulates (aerosols)
$= 3.5\times10^{-6}$ cm^2/cm^3 air for background plus local sources
$= 1.1\times10^{-5}$ cm^2/cm^3 air for urban sources

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T_a	=	Ambient air temperature (K)
T_1	=	Time period at the beginning of combustion (yr)
T_2	=	Length of exposure duration (yr)
tD	=	Time period over which deposition occurs (or time period of combustion) (yr)
T_m	=	Melting point of chemical (K)
Tp	=	Length of plant exposure to deposition per harvest of edible portion of plant (yr)
TSS	=	Total suspended solids concentration (mg/L)
T_{wk}	=	Water body temperature (K)
$t_{1/2}$	=	Half-time of COPC (days)
u	=	Current velocity (m/s)
Vdv	=	Dry deposition velocity (cm/s)
Vf_x	=	Average volumetric flow rate through water body (m^3/yr)
VG_{ag}	=	Empirical correction factor for aboveground produce (forage and silage)(unitless)
$VG_{rootveg}$	=	Empirical correction factor for belowground produce (unitless)
W	=	Average annual wind speed (m/s)
X_e	=	Unit soil loss (kg/m^2-yr)
Yh	=	Dry harvest yield = 1.22×10^{11} kg DW, calculated from the 1993 U.S. average wet weight *Yh* of 1.35×10^{11} kg (USDA 1994b) and a conversion factor of 0.9 (Fries 1994)
Yh_i	=	Harvest yield of *i*th crop (kg DW)
Yp	=	Yield or standing crop biomass of the edible portion of the plant (productivity) (kg DW/m^2)
Z_s	=	Soil mixing zone depth (cm)
0.01	=	Units conversion factor (kg cm^2/mg-m^2)
10^{-6}	=	Units conversion factor (g/µg)
10^{-6}	=	Units conversion factor (kg/mg)
0.31536	=	Units conversion factor (m-g-s/cm-µg-yr)
365	=	Units conversion factor (days/yr)
907.18	=	Units conversion factor (kg/ton)
0.1	=	Units conversion factor (g-kg/cm^2-m^2)
0.001	=	Units conversion factor (kg-cm^2/mg-m^2)
100	=	Units conversion factor (mg-cm^2/kg-cm^2)
1000	=	Units conversion factor (mg/g)
4047	=	Units conversion factor (m^2/acre)
1×10^3	=	Units conversion factor (g/kg)
3.1536×10^7	=	Units conversion factor (s/yr)

TABLE B-1-1

SOIL CONCENTRATION DUE TO DEPOSITION (SOIL INGESTION EQUATIONS)

Description

The equations in this table are used to calculate an average COPC soil concentration resulting from wet and dry deposition of particles and vapors to soil over the exposure duration. COPCs are assumed to be incorporated only to a finite depth (the soil mixing zone depth, Z_s).

The COPC soil concentration averaged over the exposure duration, represented by Cs, should be used for carcinogenic COPCs, where risk is averaged over the lifetime of an individual. Because the hazard quotient associated with noncarcinogenic COPCs is based on a reference dose rather than a lifetime exposure, the highest annual average COPC soil concentration occurring during the exposure duration period should be used for noncarcinogenic COPCs. The highest annual average COPC soil concentration would occur at the end of the time period of combustion and is represented by Cs_{tD}.

The following uncertainties are associated with this variable:

(1) The time period for deposition of COPCs resulting from hazardous waste combustion is assumed to be a conservative, long-term value. This assumption may overestimate Cs and Cs_{tD}.

(2) Exposure duration values (T_2) are based on historical mobility studies and will not necessarily remain constant. Specifically, mobility studies indicate that most receptors that move remain in the vicinity of the combustion unit; however, it is impossible to accurately predict the probability that these short-distance moves will influence exposure, based on factors such as atmospheric transport of pollutants.

(3) The use of a value of zero for T_1 does not account for exposure that may have occurred from historic operations and emissions from hazardous waste combustion. This may underestimate Cs and Cs_{tD}.

(4) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting a greater mixing depth. This uncertainty may overestimate Cs and Cs_{tD}.

(5) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate Cs and Cs_{tD}.

TABLE B-1-1

SOIL CONCENTRATION DUE TO DEPOSITION
(SOIL INGESTION EQUATIONS)

Equation for Carcinogens

Soil Concentration Averaged Over Exposure Duration

$$Cs = \frac{\left(\frac{Ds \cdot tD - Cs_{tD}}{ks}\right) + \left(\frac{Cs_{tD}}{ks} \cdot [1 - \exp(-ks(T_2 - tD))]\right)}{(T_2 - T_1)} \quad \textit{for } T_1 < tD < T_2$$

$$Cs = \frac{Ds}{ks \cdot (tD - T_1)} \cdot \left(\left[tD + \frac{\exp(-ks \cdot tD)}{ks} \right] - \left[T_1 + \frac{\exp(-ks \cdot T_1)}{ks} \right] \right) \quad \textit{for } T_2 \le tD$$

Equation for Noncarcinogens

Highest Annual Average Soil Concentration

$$Cs_{tD} = \frac{Ds \cdot [1 - \exp(-ks \cdot tD)]}{ks}$$

where

$$Ds = \frac{100 \cdot Q}{Z_s \cdot BD} \cdot [F_v \, (0.31536 \cdot Vdv \cdot Cyv + Dywv) + (Dydp + Dywp) \cdot (1 - F_v)]$$

For mercury modeling

$$Ds = \frac{100 \cdot (0.48Q)}{Z_s \cdot BD} \cdot [F_v \, (0.31536 \cdot Vdv \cdot Cyv + Dywv) + (Dydp + Dywp) \cdot (1 - F_v)]$$

Use *0.48Q* for total mercury and $F_v = 0.85$ in the mercury modeling equation to calculate *Ds*. The calculated *Ds* value is apportioned into the divalent mercury (Hg^{2+}) and methyl mercury (MHg) forms based on the assumed 98% Hg^{2+} and 2% MHg speciation split in soils (see Chapter 2). Elemental mercury (Hg^0) occurs in very small amounts in the vapor phase and does not exist in the particle or particle-bound phase. Therefore, elemental mercury deposition onto soils is assumed to be negligible or zero. Elemental mercury is evaluated for the direct inhalation pathway only (Table B-5-1).

Ds (Hg^{2+})	=	0.98 *Ds*
Ds (Mhg)	=	0.02 *Ds*
Ds (Hg^0)	=	0.0

Evaluate divalent and methyl mercury as individual COPCs. Calculate *Cs* for divalent and methyl mercury using the corresponding (1) fate and transport parameters for mercuric chloride (Hg^{2+}) and methyl mercury provided in Appendix A-3, and (2) *Ds* (Hg^{2+}) and *Ds* (MHg) as calculated above.

TABLE B-1-1

SOIL CONCENTRATION DUE TO DEPOSITION (SOIL INGESTION EQUATIONS)

Variable	Description	Units	Value
Cs	Average soil concentration over exposure duration	mg COPC/kg soil	
Cs_{tD}	Soil concentration at time *tD*	mg COPC/kg soil	
Ds	Deposition term	mg COPC/kg soil-yr	**Varies** U.S. EPA (1994a) and NC DEHNR (1997) recommend incorporating the use of a deposition term into the *Cs* equation. Uncertainties associated with this variable include the following: (1) Four of the variables in the equation for *Ds* (*Q*, *Cywv*, *Dywv*, *Dydp*, and *Dywp*) are COPC- and site-specific. Values of these variables are estimated on the basis of modeling. The direction and magnitude of any uncertainties should not be generalized. (2) Based on the narrow recommended ranges, uncertainties associated with *Vdv*, F_v, and *BD* are expected to be low. (3) Values for Z_s vary by about one order of magnitude. Uncertainty is greatly reduced if it is known whether soils are tilled or untilled.
tD	Time period over which deposition occurs (time period of combustion)	yr	**100** U.S. EPA (1990a) specifies that this period of time can be represented by periods of 30, 60 or 100 years. U.S. EPA OSW recommends that facilities use the conservative value of 100 years unless site-specific information is available indicating that this assumption is unreasonable (see Chapter 6 of the HHRAP).
ks	COPC soil loss constant due to all processes	yr^{-1}	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-1-2. The COPC soil loss constant is the sum of all COPC removal processes. Uncertainty associated with this variable includes the following: COPC-specific values for *ksg* (one of the variables in the equation in Table B-1-2) are empirically determined from field studies. No information is available regarding the application of these values to the site-specific conditions associated with affected facilities.

TABLE B-1-1

SOIL CONCENTRATION DUE TO DEPOSITION (SOIL INGESTION EQUATIONS)

Variable	Description	Units	Value
T_2	Length of exposure duration	yr	**6, 30, or 40** U.S. EPA OSW recommends reasonable maximum exposure (RME) values for T_2: Exposure Duration — RME — Reference Child Resident, Subsistence Farmer Child, Subsistence Fisher Child — 6 years — U.S. EPA (1990b) Adult Resident and Subsistence Fisher — 30 years (6 child and 24 adult) — U.S. EPA (1990b) Subsistence Farmer — 40 years — U.S. EPA (1994b) U.S. EPA (1994c) recommended the following unreferenced values: Exposure Duration — Years Subsistence Farmer — 40 Adult Resident — 30 Subsistence Fisher — 30 Child Resident — 9 Uncertainties associated with this variable include the following: (1) Exposure duration rates are based on historical mobility rates and may not remain constant. This assumption may overestimate or underestimate Cs and Cs_{tD}. (2) Mobility studies indicate that most receptors that move remain in the vicinity of the emission sources. However, it is impossible to accurately predict the likelihood that these short-distance moves will influence exposure, based on factors such as atmospheric transport of pollutants. This assumption may overestimate or underestimate Cs and Cs_{tD}.
T_1	Time period at the beginning of combustion	yr	**0** Consistent with U.S. EPA (1994c), U.S. EPA OSW recommends a value of 0 for T_1. The following uncertainty is associated with this variable: The use of a value of 0 for T_1 does not account for exposure that may have occurred from historical operations or emissions from the combustion of hazardous waste. This may underestimate Cs and Cs_{tD}.

TABLE B-1-1

SOIL CONCENTRATION DUE TO DEPOSITION (SOIL INGESTION EQUATIONS)

Variable	Description	Units	Value
100	Units conversion factor	mg-cm²/kg-cm²	
Q	COPC-specific emission rate	g/s	**Varies** This variable is COPC- and site-specific. See Chapters 2 and 3 of the HHRAP for guidance regarding the calculation of this variable. Uncertainties associated with this variable are site-specific.
Z_s	Soil mixing zone depth	cm	**1 to 20** U.S. EPA OSW recommends the following values for this variable: Soil / Depth (cm) / Reference Untilled / 1 / U.S. EPA (1990a) and U.S. EPA (1993a) Tilled / 20 / U.S. EPA (1990a) and U.S. EPA (1993a) U.S. EPA (1990a) did not include a reference for these values. U.S. EPA (1993a) cites U.S. EPA (1992). The following uncertainties are associated with this variable: (1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting a greater mixing depth. This uncertainty may overestimate *Cs* and Cs_{tD}. (2) Deposition to hard surfaces may result in dust residues that have negligible dilution in comparison to that of other residues. This uncertainty may underestimate *Cs* and Cs_{tD}.
BD	Soil bulk density	g soil/cm³ soil	**1.5** This variable is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil (Hillel 1980), as summarized in U.S. EPA (1990a). A range of 0.83 to 1.84 was originally cited in Hoffman and Baes (1979). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g soil/cm³ soil, based on a mean value for loam soil that was obtained from Carsel, Parrish, Jones, Hansen, and Lamb (1988). The value of 1.5 g soil/cm³ soil also represents the midpoint of the "relatively narrow range" for *BD* of 1.2 to 1.7 g soil/cm³ soil (U.S. EPA 1993a). The following uncertainty is associated with this variable: The recommended *BD* value may not accurately represent site-specific soil conditions; and may under- or overestimate site-specific soil conditions to an unknown degree.

Variable	Description	Units	Value
F_v	Fraction of COPC air concentration in vapor phase	unitless	**0 to 1** This variable is COPC-specific. Discussion of this variable and COPC-specific values are presented in Appendix A-3. This range is based on the values presented in Appendix A-3. Values are also presented in U.S. EPA (1994c) and NC DEHNR (1997). F_v was calculated using an equation presented in Junge (1977) for all organic COPCs, including PCDDs and PCDFs. U.S. EPA (1994c) states that $F_v = 0$ for all metals (except mercury). The following uncertainties are associated with this variable: (1) It is based on the assumption of a default S_T values for background plus local sources, rather than an S_T value for urban sources. If a specific site is located in an urban area, the use of the latter S_T value may be more appropriate. Specifically, the S_T value for urban sources is about one order of magnitude greater than that for background plus local sources, and it would result in a lower calculated F_v value; however, the F_v value is likely to be only a few percent lower. (2) According to Bidleman (1988), the equation used to calculate F_v assumes that the variable *c* (Junge constant) is constant for all chemicals; however, the value of *c* depends on the chemical (sorbate) molecular weight, the surface concentration for monolayer coverage, and the difference between the heat of desorption from the particle surface and the heat of vaporization of the liquid-phase sorbate. To the extent that site- or COPC-specific conditions may cause the value of *c* to vary, uncertainty is introduced if a constant value of *c* is used to calculate F_v.
0.31536	Units conversion factor	m-g-s/cm-µg-yr	
Vdv	Dry deposition velocity	cm/s	**3** U.S. EPA (1994c) recommended the use of 3 cm/s for the dry deposition velocity, based on median dry deposition velocity for HNO_3 from an unspecified U.S. EPA database of dry deposition velocities for HNO_3, ozone, and SO_2. HNO_3 was considered the most similar to the COPCs recommended for consideration in the HHRAP. The value should be applicable to any organic COPC with a low Henry's Law Constant. The following uncertainty is associated with this variable: HNO_3 may not adequately represent specific COPCs; therefore, the use of a single value may under- or overestimate estimated soil concentration.
Cyv	Unitized yearly average air concentration from vapor phase	µg-s/g-m^3	**Varies** This variable is COPC- and site-specific, and is determined by air modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.

SOIL CONCENTRATION DUE TO DEPOSITION (SOIL INGESTION EQUATIONS)

Variable	Description	Units	Value
Dywv	Unitized yearly average wet deposition from vapor phase	s/m^2-yr	**Varies** This variable is COPC- and site-specific, and is determined by air modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.
Dydp	Unitized yearly average dry deposition from particle phase	s/m^2-yr	**Varies** This variable is COPC- and site-specific, and is determined by air modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.
Dywp	Unitized yearly average wet deposition from particle phase	s/m^2-yr	**Varies** This variable is COPC- and site-specific, and is determined by air modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.

REFERENCES AND DISCUSSION

Bidleman, T.F. 1988. "Atmospheric Processes." *Environmental Science and Technology.* Volume 22. Number 4. Pages 361-367.

This reference is for the statement that the equation used to calculate the fraction of air concentration in vapor phase (F_v) assumes that the variable c (the Junge constant) is constant for all chemicals. However, this document notes that the value of c depends on the chemical (sorbate) molecular weight, the surface concentration for monolayer coverage, and the difference between the heat of desorption from the particle surface and the heat of vaporization of the liquid phase sorbate. The following equation, presented in this document, is cited by U.S. EPA (1994b) and NC DEHNR (1997) for calculating the variable F_v:

$$F_v = 1 - \frac{c \cdot S_T}{P^\circ_L - c \cdot S_T}$$

where

F_v	=	Fraction of chemical air concentration in vapor phase (unitless)
c	=	Junge constant = 1.7×10^{-04} (atm-cm)
S_T	=	Whitby's average surface area of particulates = 3.5×10^{-06} cm^2/cm^3 air (corresponds to background plus local sources)
P°_L	=	Liquid-phase vapor pressure of chemical (atm) (see Appendix A-3)

If the chemical is a solid at ambient temperatures, the solid-phase vapor pressure is converted to a liquid-phase vapor pressure as follows:

$$\ln \frac{P^\circ_L}{P^\circ_S} = \frac{\Delta S_f}{R} \cdot \frac{(T_m - T_a)}{T_a}$$

where

P°_S	=	Solid-phase vapor pressure of chemical (atm) (see Appendix A-3)
$\frac{\Delta S_f}{R}$	=	Entropy of fusion over the universal gas constant = 6.79 (unitless)
T_m	=	Melting point of chemical (K) (see Appendix A-3)
T_a	=	Ambient air temperature = 284 K (11°C)

Carsel, R.F., R.S. Parrish, R.L. Jones, J.L. Hansen, and R.L. Lamb. 1988. "Characterizing the Uncertainty of Pesticide Leaching in Agricultural Soils." *Journal of Contaminant Hydrology*. Vol. 2. Pages 11-24.

This reference is cited by U.S. EPA (1994b) as the source for a mean soil bulk density value, *BD*, of 1.5 g soil/cm^3 soil for loam soil.

Hillel, D. 1980. *Fundamentals of Soil Physics*. Academic Press, Inc. New York.

This document is cited by U.S. EPA (1990a) for the statement that soil bulk density, *BD*, is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil.

Hoffman, F.O., and C.F. Baes, 1979. *A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides.* ORNL/NOREG/TM-882.

This document presents a soil bulk density range, *BD*, of 0.83 to 1.84.

Junge, C.E. 1977. *Fate of Pollutants in Air and Water Environments, Part I.* Suffet, I.H., Ed. Wiley. New York. Pages 7-26.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This is one of the source documents for the equation in Table B-1-1. This document also recommends the use of (1) a deposition term, *Ds*, and (2) COPC-specific F_v (fraction of COPC air concentration in vapor phase) values.

Research Triangle Institute (RTI). 1992. *Preliminary Soil Action Level for Superfund Sites.* Draft Interim Report. Prepared for U.S. EPA Hazardous Site Control Division, Remedial Operations Guidance Branch. Arlington, Virginia. EPA Contract 68-W1-0021. Work Assignment No. B-03, Work Assignment Manager Loren Henning. December.

This document is a reference source for COPC-specific F_v (fraction of COPC air concentration in vapor phase) values.

U.S. EPA. 1990a. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600-90-003. January.

This document is a reference source for the equation in Table B-1-1, and it recommends that (1) the time period over which deposition occurs (time period for combustion), *tD*, be represented by periods of 30, 60, and 100 years, and (2) undocumented values for soil mixing zone depth, Z_s, for tilled and untilled soil.

U.S. EPA. 1990b. *Exposure Factors Handbook.* March.

This document is a reference source for values for length of exposure duration, T_2.

U.S. EPA. 1992. *Estimating Exposure to Dioxin-Like Compounds.* Draft Report. Office of Research and Development. Washington, D.C. EPA/600/6-88/005b.

This document is cited by U.S. EPA (1993a) as the source of values for soil mixing zone depth, Z_s, for tilled and untilled soils.

U.S. EPA. 1993a. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, D.C. November.

This document is a reference for recommended values for soil mixing zone depth, Z_s, for tilled and untilled soils; it cites U.S. EPA (1992) as the source of these values. It also recommends a "relatively narrow" range for soil bulk density, *BD*, of 1.2 to 1.7 g soil/cm^3 soil.

U.S. EPA. 1993b. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Working Group Recommendations. Office of Solid Waste. Office of Research and Development. Washington, D.C. September 24.

This document is a reference for the equation in Table B-1-1. It recommends using a deposition term, *Ds*, and COPC-specific F_v values (fraction of COPC air concentration in vapor phase) in the *Cs* equation.

U.S. EPA 1994a. *Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. April 15.

This document is a reference for the equation in Table B-1-1; it recommends that the following be used in the *Cs* equation: (1) a deposition term, *Ds*, and (2) a default soil bulk density value of 1.5 g soil/cm^3 soil, based on a mean value for loam soil from Carsel, Parrish, Jones, Hansen, and Lamb (1988).

U.S. EPA. 1994b. *Estimating Exposure to Dioxin-Like Compounds. Volume III: Site-Specific Assessment Procedures.* External Review Draft. Office of Research and Development. Washington, D.C. EPA/600/6-88/005Cc. June.

This document recommends values for length of exposure duration, T_2, for the subsistence farmer.

U.S. EPA. 1994c. *Revised Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

The value for dry deposition velocity is based on median dry deposition velocity for HNO_3 from a U.S. EPA database of dry deposition velocities for HNO3 ozone, and SO_2. HNO_3 was considered the most similar to the constituents covered and the value should be applicable to any organic compound having a low Henry's Law Constant. The reference document for this recommendation was not cited. This document recommends the following:

- Values for the length of exposure duration, T_2
- Value of 0 for the time period of the beginning of combustion, T_1
- F_v values (fraction of COPC air concentration in vapor phase) that range from 0.27 to 1 for organic COPCs
- *Vdv* value (dry deposition velocity) of 3 cm/s (however, no reference is provided for this recommendation)
- Default soil bulk density value of 1.5 g soil/cm^3 soil, based on a mean for loam soil from Carsel, Parrish, Jones, Hansen, and Lamb (1988)
- *Vdv* value of 3 cm/s, based on median dry deposition velocity for HNO_3 from an unspecified U.S. EPA database of dry deposition velocities for HNO_3, ozone, and SO_2. HNO_3 was considered the most similar to the COPCs recommended for consideration in the HHRAP.

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

TABLE B-1-2

COPC SOIL LOSS CONSTANT (SOIL INGESTION EQUATIONS)

(Page 1 of 4)

Description
This equation calculates the COPC soil loss constant, which accounts for the loss of COPCs from soil by several mechanisms. Uncertainties associated with this equation include the following: (1) COPC-specific values for *ksg* are empirically determined from field studies; no information is available regarding the application of these values to the site-specific conditions associated with affected facilities. (2) The source of the equations in Tables B-1-3 through B-1-6 have not been identified.

Equation

$$ks = ksg + kse + ksr + ksl + ksv$$

Variable	Description	Units	Value
ks	COPC soil loss constant due to all processes	yr^{-1}	
ksg	COPC loss constant due to biotic and abiotic degradation	yr^{-1}	**Varies** This variable is COPC-specific and should be determined from the COPC tables in Appendix A-3. "Degradation rate" values are also presented in NC DEHNR (1997); however, no reference or source is provided for the values. U.S. EPA (1994a) and U.S. EPA (1994b) state that *ksg* values are COPC-specific; however, all *ksg* values are presented as zero (U.S. EPA 1994a) or as "NA" (U.S. EPA 1994b); the basis of these assumptions is not addressed. The following uncertainty is associated with this variable: COPC-specific values for *ksg* are empirically determined from field studies; no information is available regarding the application of these values to the site-specific conditions associated with affected facilities.

TABLE B-1-2

COPC SOIL LOSS CONSTANT (SOIL INGESTION EQUATIONS)

Variable	Description	Units	Value
kse	COPC loss constant due to soil erosion	yr^{-1}	**0** This variable is COPC- and site-specific, and is further discussed in Table B-1-3. Consistent with U.S. EPA (1994a), U.S. EPA (1994b) and NC DEHNR (1997), U.S. EPA OSW recommends that the default value assumed for *kse* is zero because of contaminated soil eroding onto the site and away from the site. Uncertainties associated with this variable include the following: (1) The source of the equation in Table B-1-3 has not been identified. (2) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting a greater mixing depth. This uncertainty may overestimate *kse*. (3) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *kse*.
ksr	COPC loss constant due to surface runoff	yr^{-1}	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-1-4. No reference document is cited for this equation; however, the use of this equation is consistent with U.S. EPA (1993). U.S. EPA (1994a) states that all *ksr* values are zero but does not explain the basis for this assumption. Uncertainties associated with this variable (calculated by using the equation in Table B-1-4) include the following: (1) The source of the equation in Table B-1-4 has not been identified. (2) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting a greater mixing depth. This uncertainty may overestimate *ksr*. (3) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksr*.
ksl	COPC loss constant due to leaching	yr^{-1}	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-1-5. The use of this equation is consistent with U.S. EPA (1993), U.S. EPA (1994b), and NC DEHNR (1997). U.S. EPA (1994a) states that all *ksl* values are zero but does not explain the basis of this assumption. Uncertainties associated with this variable (calculated by using the equation in Table B-1-5) include the following: (1) The source of the equation in Table B-1-5 has not been identified. (2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksl*.

TABLE B-1-2

COPC SOIL LOSS CONSTANT
(SOIL INGESTION EQUATIONS)

Variable	Description	Units	Value
ksv	COPC loss constant due to volatilization	yr^{-1}	**0** This variable is COPC- and site-specific, and is further discussed in Table B-1-6. Consistent with U.S. EPA guidance (1994a) and based on the need for additional research to be conducted to determine the magnitude of the uncertainty introduced for modeling volatile COPCs from soil, U.S. EPA OSW recommends that, until identification and validation of more applicable models, the constant for the loss of soil resulting from volatilization (*ksv*) should be set equal to zero. Uncertainties associated with this variable include the following: (1) The source of the equation in Table B-1-6 has not been identified. (2) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting a greater mixing depth. This uncertainty may overestimate *ksv*. (3) Deposition to hard surfaces may result in dust residues that have negligible dilution, (as a result of potential mixing with in-situ materials) in comparison to that of other residues. This uncertainty may underestimate *ksv*.

REFERENCES AND DISCUSSION

NC DEHNR. 1997. *Final NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is one of the reference documents for the equations in Tables B-1-4, B-1-5, and B-1-6. This document is also cited as (1) the source for a range of COPC-specific degradation rates (*ksg*), and (2) one of the sources that recommend using the assumption that the loss resulting from erosion (*kse*) is zero because of contaminated soil eroding onto the site and away from the site.

U.S. EPA. 1993. *Review Draft Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Office of Health and Environmental Assessment. Office of Research and Development. EPA-600-AP-93-003. November 10.

This document is one of the reference documents for the equations in Tables B-1-3 and B-1-5.

U.S. EPA. 1994a. *Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* April 15.

This document is cited as a source for the assumptions that losses resulting from erosion (*kse*), surface runoff (*ksr*), degradation (*ksg*), leaching (*ksl*), and volatilization (*ksv*) are all zero.

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document is one of the reference documents for the equations in Tables B-1-4, B-1-5, and B-1-6. This document is also cited as one of the sources that recommend using the assumption that the loss resulting from erosion (*kse*) is zero and the loss resulting from degradation (*ksg*) is "NA" or zero for all compounds.

COPC LOSS CONSTANT DUE TO SOIL EROSION (SOIL INGESTION EQUATIONS)

Description

This equation calculates the constant for COPC loss resulting from erosion of soil. Consistent with U.S. EPA (1994), U.S. EPA (1994b), and NC DEHNR (1997), U.S. EPA OSW recommends that the default value assumed for *kse* is zero because of contaminated soil eroding onto the site and away from the site. In site-specific cases where the permitting authority considers it appropriate to calculate a *kse*, the following equation presented in this table should be considered along with associated uncertainties. Additional discussion on the determination of *kse* can be obtained from review of the methodologies described in U.S. EPA NCEA document, *Methodology for Assessing Health Risks Associated with Multiple Exposure Pathways to Combustor Emissions* (In Press). Uncertainties associated with this equation include:

(1) For soluble COPCs, leaching might lead to movement below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *kse*.

(2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *kse*.

Equation

$$kse = \frac{0.1 \cdot X_e \cdot SD \cdot ER}{BD \cdot Z_s} \cdot \left(\frac{Kd_s \cdot BD}{\theta_{sw} + (Kd_s \cdot BD)} \right)$$

Variable	Description	Units	Value
kse	COPC loss constant due to soil erosion	yr^{-1}	**0** Consistent with U.S. EPA (1994), U.S. EPA (1994b), and NC DEHNR (1997), U.S. EPA OSW recommends that the default value assumed for *kse* is zero because of contaminated soil eroding onto the site and away from the site. uncertainty may overestimate *kse*.
0.1	Units conversion factor	g-kg/cm^2-m^2	
X_e	Unit soil loss	kg/m^2-yr	**Varies** This variable is site-specific and is calculated by using the equation in Table B-4-13. The following uncertainty is associated with this variable: All of the equation variables are site-specific. Use of default values rather than site-specific values for any or all of these variables will result in unit soil loss (X_e) estimates that are under- or overestimated to some degree. Based on default values, X_e estimates can vary over a range of less than two orders of magnitude.

Variable	Description	Units	Value
SD	Sediment delivery ratio	unitless	**Varies** This value is site-specific, and is calculated by using the equation in Table B-4-14. Uncertainties associated with this variable include the following: (1) The recommended default values for the empirical intercept coefficient, *a*, are average values that are based on studies of sediment yields from various watersheds. Therefore, those default values may not accurately represent site-specific watershed conditions. As a result, use of these default values may under- or overestimate *SD*. (2) The recommended default value for the empirical slope coefficient, *b*, is based on a review of sediment yields from various watersheds. This single default value may not accurately represent site-specific watershed conditions. As a result, use of this default value may under- or overestimate *SD*.
ER	Soil enrichment ratio	unitless	**Inorganics: 1** **Organics: 3** COPC enrichment occurs because (1) lighter soil particles erode more than heavier soil particles, and (2) concentration of organic COPCs—which is a function of organic carbon content of sorbing media—is expected to be higher in eroded material than in *in-situ* soil (U.S. EPA 1993). In the absence of site-specific data, U.S. EPA OSW recommends a default value of 3 for organic COPCs and 1 for inorganic COPCs. This is consistent with other U.S. EPA guidance (1993), which recommends a range of 1 to 5 and a value of 3 as a "reasonable first estimate." This range has been used for organic matter, phosphorus, and other soil-bound COPCs (U.S. EPA 1993); however, no sources or references were provided for this range. *ER* is generally higher in sandy soils than in silty or loamy soils (U.S. EPA 1993). The following uncertainty is associated with this variable: The default *ER* value may not accurately reflect site-specific conditions; therefore, *kse* may be over- or underestimated to an unknown extent. The extent of any uncertainties will be reduced by using county-specific *ER* values.
BD	Soil bulk density	g soil/cm^3 soil	**1.5** This variable is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil (Hillel 1980), as summarized in U.S. EPA (1990). A range of 0.83 to 1.84 was originally cited in Hoffman and Baes (1979). U.S. EPA (1994b) recommended a default *BD* value of 1.5 g soil/cm^3 soil, based on a mean value for loam soil that was taken from Carsel, Parrish, Jones, Hansen, and Lamb (1988). The value of 1.5 g soil/cm^3 soil also represents the midpoint of the "relatively narrow range" for *BD* of 1.2 to 1.7 g soil/cm^3 soil (U.S. EPA 1993). The following uncertainty is associated with this variable: The recommended soil bulk density value may not accurately represent site-specific soil conditions.

TABLE B-1-3

COPC LOSS CONSTANT DUE TO SOIL EROSION
(SOIL INGESTION EQUATIONS)

Variable	Description	Units	Value
Z_s	Soil mixing zone depth	cm	**1 to 20** U.S. EPA currently recommends the following values for this variable: Soil / Depth (cm) / Reference Untilled / 1 / U.S. EPA (1990a) and U.S. EPA (1993a) Tilled / 20 / U.S. EPA (1990a) and U.S. EPA (1993a) U.S. EPA (1990) does not provide a reference for these values. U.S. EPA (1993) cites U.S. EPA (1994a). Uncertainties associated with this variable include the following: (1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *kse.* (2) Deposition to hard surfaces may result in dust residues that have negligible dilution in comparison to that of other residues. This uncertainty may underestimate *kse*.
Kd_s	Soil-water partition coefficient	mL water/g soil (or cm^3 water/g soil)	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Uncertainties associated with this parameter will be limited if Kd_s values are calculated as described in Appendix A-3.
θ_{sw}	Soil volumetric water content	mL water/cm^3 soil	**0.2** This variable is site-specific, and depends on the available water and on soil structure; θ_{sw} can be estimated as the midpoint between a soil's field capacity and wilting point, if a representative watershed soil can be identified. However, U.S. EPA OSW recommends the use of 0.2 mL/cm^3 as a default value. This value is the midpoint of the range 0.1 (very sandy soils) to 0.3 (heavy loam/clay soils) recommended by U.S. EPA (1993) (no source or reference is provided for this range) and is consistent with U.S. EPA (1994b). The following uncertainty is associated with this variable: The default θ_{sw} value may not accurately reflect site-specific or local conditions; therefore, *kse* may be under- or overestimated to a small extent, based on the limited range of values.

REFERENCES AND DISCUSSION

Carsel, R.F., R.S. Parish, R.L. Jones, J.L. Hansen, and R.L. Lamb. 1988. "Characterizing the Uncertainty of Pesticide Leaching in Agricultural Soils." *Journal of Contaminant Hydrology*. Vol. 2. Pages 11-24.

This document is cited by U.S. EPA (1994b) as the source for a mean soil bulk density, *BD*, value of 1.5 g soil/cm^3 soil for loam soil.

Hillel, D. 1980. *Fundamentals of Soil Physics*. Academic Press, Inc. New York.

This document is cited by U.S. EPA (1990) for the statement that soil bulk density, *BD*, is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil.

Hoffman, F.O., and C.F. Baes. 1979. *A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides.* ORNL/NUREG/TM-882.

This document presents a soil bulk density, *BD*, range of 0.83 to 1.84.

NC DEHNR. 1997. *Final NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is one of the sources that recommend using the assumption that the loss resulting from erosion (*kse*) is zero because of contaminated soil eroding onto the site and away from the site.

U.S. EPA. 1993. *Review Draft Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Office of Health and Environmental Assessment. Office of Research and Development. EPA-600-AP-93-003. November 10.

This document is one of the reference documents for the equations in Tables B-1-3 and B-1-5.

U.S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600-90-003. January.

This document presents a range of values for soil mixing zone depth, Z_s, for tilled and untilled soil. The basis or source of these values is not identified.

U.S. EPA. 1993. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, D.C. November 1993.

This document is the source of a range of COPC enrichment ratio, *ER*, values. The recommended range, 1 to 5, has been used for organic matter, phosphorous, and other soul-bound COPCs. This document recommends a value of 3 as a "reasonable first estimate," and states that COPC enrichment occurs because lighter soil particles erode more than heavier soil particles. Lighter soil particles have higher ratios of surface area to volume and are higher in organic matter content. Therefore, concentration of organic COPCs, which is a function of the organic carbon content of sorbing media, is expected to be higher in eroded material than in *insitu* soil.

This document is also a source of the following:

- A "relatively narrow range" for soil bulk density, *BD*, of 1.2 to 1.7 g soil/cm^3 soil
- COPC-specific (inorganic COPCs only) Kd_s values used to develop a proposed range (2 to 280,000 mL water/g soil) of Kd_s values
- A range of soil volumetric water content (θ_{sw}) values of 0.1 mL water/cm^3 soil (very sandy soils) to 0.3 mL water/cm^3 soil (heavy loam/clay soils) (however, no source or reference is provided for this range)
- A range of values for soil mixing zone depth, Z_s, for tilled and untilled soil

U.S. EPA. 1994. *Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* April 15.

U.S. EPA. 1994a. *Estimating Exposure to Dioxin-Like Compounds. Volume III: Site-specific Assessment Procedures.* External Review Draft. Office of Research and Development. Washington, D.C. EPA/600/6-88/005Cc. June.

This document is the source of values for soil mixing zone depth, Z_s, for tilled and untilled soil, as cited in U.S. EPA (1993).

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document recommends (1) a default soil bulk density value of 1.5 g soil/cm^3 soil, based on a mean value for loam soil that is taken from Carsel, Parrish, Jones, Hansen, and Lamb (1988), and (2) a default soil volumetric water content, θ_{sw}, value of 0.2 mL water/cm^3 soil, based on U.S. EPA (1993).

TABLE B-1-4

COPC LOSS CONSTANT DUE TO RUNOFF
(SOIL INGESTION EQUATIONS)

Description

This equation calculates the COPC loss constant due to runoff of soil. Uncertainties associated with this equation include the following:

(1) For soluble COPCs, leaching might result in movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksr*.
(2) Deposition to hard surfaces may result in dust residues that have negligible dilution in comparison to that of other residues. This uncertainty may underestimate *ksr*.

Equation

$$ksr = \frac{RO}{\theta_{sw} \cdot Z_s} \cdot \left(\frac{1}{1 + (Kd_s \cdot BD / \theta_{sw})} \right)$$

Variable	Description	Units	Value
ksr	COPC loss constant due to runoff	yr^{-1}	
RO	Average annual surface runoff from pervious areas	cm/yr	**Varies** This variable is site-specific. According to U.S. EPA (1993), U.S. EPA (1994b), and NC DEHNR (1997), average annual surface runoff, *RO*, can be estimated by using the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973). According to NC DEHNR (1997), estimates can also be made by using more detailed, site-specific procedures for estimating the amount of surface runoff, such as those based on the U.S. Soil Conservation Service curve number equation (CNE). U.S. EPA (1985) is cited as an example of such a procedure. The following uncertainty is associated with this variable: To the extent that site-specific or local average annual surface runoff information is not available, default or estimated values may not accurately represent site-specific or local conditions. As a result, *ksl* may be under- or overestimated to an unknown degree.

TABLE B-1-4

COPC LOSS CONSTANT DUE TO RUNOFF (SOIL INGESTION EQUATIONS)

Variable	Description	Units	Value
θ_{sw}	Soil volumetric water content	mL water/cm^3 soil	**0.2** This variable depends on the available water and soil structure; if a representative watershed soil can be identified, θ_{sw} can be estimated as the midpoint between a soil's field capacity and wilting point. U.S. EPA OSW recommends the use of 0.2 mL/cm^3 as a default value. This value is the midpoint of the range 0.1 (very sandy soils) to 0.3 (heavy loam/clay soils), which is recommended by U.S. EPA (1993) (no source or reference is provided for this range), and is consistent with U.S. EPA (1994b) and NC DEHNR (1997). The following uncertainty is associated with this variable: The default θ_{sw} value may not accurately reflect site-specific or local conditions; therefore, *kse* may be under- or overestimated to a small extent, based on the limited range of values.
Z_s	Soil mixing zone depth	cm	**1 to 20** U.S. EPA OSW recommends the following values for this variable: Soil / Depth (cm) / Reference Untilled / 1 / U.S. EPA (1990a) and U.S. EPA (1993a) Tilled / 20 / U.S. EPA (1990a) and U.S. EPA (1993a) U.S. EPA (1990) does not provide a reference for these values. U.S. EPA (1993a) cites U.S. EPA (1994a). Uncertainties associated with this variable include the following: (1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksr*. (2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksr*.
Kd_s	Soil-water partition coefficient	mL water/g soil (or cm^3 water/g soil)	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Uncertainties associated with this parameter will be limited if Kd_s values are calculated as described in Appendix A-3.

TABLE B-1-4

COPC LOSS CONSTANT DUE TO RUNOFF (SOIL INGESTION EQUATIONS)

Variable	Description	Units	Value
BD	Soil bulk density	g soil/cm^3 soil	**1.5** This variable is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil (Hillel 1980), as summarized in U.S. EPA (1990). The proposed range was originally cited in Hoffman and Baes (1979). U.S. EPA (1994b) recommended a default soil bulk density value of 1.5 (g soil/cm^3 soil), based on a mean value for loam soil that is taken from Carsel, Parrish, Jones, Hansen, and Lamb (1988). The value of 1.5 (g soil/cm^3 soil) also represents the midpoint of the "relatively narrow range" for *BD* of 1.2 to 1.7 (g soil/cm^3 soil) (U.S. EPA 1993). The following uncertainty is associated with this variable: The recommended soil bulk density value may not accurately represent site-specific soil conditions.

REFERENCES AND DISCUSSION

Carsel, R.F., R.S. Parrish, R.L. Jones, J.L. Hansen, and R.L. Lamb. 1988. "Characterizing the Uncertainty of Pesticide Leaching in Agricultural Soils." *Journal of Contaminant Hydrology*. Vol. 2. Pages 11-24.

This document is cited by U.S. EPA (1994b) as the source of a mean soil bulk density, *BD*, value of 1.5 (g soil/cm^3 soil) for loam soil.

Geraghty, J.J., D.W. Miller, F. Van der Leeden, and F.L. Troise. 1973. *Water Atlas of the United States.* Water Information Center, Port Washington, New York.

This document is cited by U.S. EPA (1993), U.S. EPA (1994), and NC DEHNR (1997) as a reference to calculate average annual runoff, *RO*. This reference provides maps with isolines of annual average surface water runoff, which is defined as all flow contributions to surface water bodies, including direct runoff, shallow interflow, and ground water recharge. Because these values are total contributions and not only surface runoff, U.S. EPA (1994) recommends that the volumes be reduced by 50 percent in order to estimate surface runoff.

Hillel, D. 1980. Fundamentals of Soil Physics. Academic Press, Inc. New York.

This document is cited by U.S. EPA (1990) for the statement that soil bulk density, *BD*, is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil.

Hoffman, F.O., and C.F. Baes. 1979. *A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides.* ORNL/NUREG/TM-882.

This document presents a soil bulk density, *BD*, range of 0.83 to 1.84.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is one of the source documents that cites the use of Table B-1-4; however, this document is not the original source of this equation (this source is unknown). This document also recommends the following:

- Estimation of annual current runoff, *RO* (cm/yr), by using the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973) or site-specific procedures, such as using the U.S. Soil Conservation Service curve number equation (CNE); U.S. EPA (1985) is cited as an example of such a procedure.
- Default value of 0.2 (mL water/cm^3 soil) for soil volumetric water content (θ_{sw})

U.S. EPA. 1985. *Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water—Part I (Revised. 1985).* Environmental Research Laboratory. Athens, Georgia. EPA/600/6-85/002a. September.

This document is cited by NC DEHNR (1997) as an example of the use of the U.S. Soil Conservation Service CNE to estimate site-specific surface runoff.

U.S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600-90-003. January.

This document presents a range of values for soil mixing zone depth, Z_s, for tilled and untilled soil; the basis for, or sources of, these values is not identified.

U.S. EPA. 1993. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, D.C. November.

This document recommends the following:

- A "relatively narrow range" for soil bulk density, *BD*, of 1.2 to 1.7 (g soil/cm^3 soil)
- A range of soil volumetric water content, θ_{sw}, values of 0.1 (very sandy soils) to 0.3 (heavy loam/clay soils) (the original source of, or reference for, these values is not identified)
- A range of values for soil mixing depth, Z_s, for tilled and untilled soil (the original source of, or reference for, these values is not identified)
- A range (2 to 280,000 [mL water/g soil]) of Kd_s values for inorganic COPCs
- Use of the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973) to calculate average annual runoff, *RO*

U.S. EPA. 1994a. *Estimating Exposure to Dioxin-Like Compounds. Volume III: Site-specific Assessment Procedures.* External Review Draft. Office of Research and Development. Washington, D.C. EPA/600/6-88/005Cc. June.

This document presents a range of values for soil mixing zone depth, Z_s, for tilled and untilled soil as cited in U.S. EPA (1993).

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes.* Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities. Offices of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document recommends the following:

- Estimation of average annual runoff, *RO*, by using the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973)
- Default soil bulk density, *BD*, value of 1.5 g soil/cm^3 soil, based on the mean for loam soil that is taken from Carsel, Parrish, Jones, Hansen, and Lamb (1988)
- Default soil volumetric water content, θ_{sw}, value of 0.2 (mL water/cm^3 soil), based on U.S. EPA (1993)

COPC LOSS CONSTANT DUE TO LEACHING
(SOIL INGESTION EQUATIONS)

Description

This equation calculates the constant for COPC loss resulting from leaching of soil. Uncertainties associated with this equation include the following:

(1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksl*.
(2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksl*.
(3) The original source of this equation has not been identified. U.S. EPA (1993) presents the equation as shown here. U.S. EPA (1994b) and NC DEHNR (1997) replaced the numerator as shown with "*q*", defined as average annual recharge (cm/yr).

Equation

$$ksl = \frac{P + I - RO - E_v}{\theta_{sw} \cdot Z_s \cdot \left[1.0 + \left(BD \cdot Kd_s / \theta_{sw}\right)\right]}$$

Variable	Description	Units	Value
ksl	COPC loss constant due leaching	yr^{-1}	
P	Average annual precipitation	cm/yr	**18.06 to 164.19** This variable is site-specific. This range is based on information presented in U.S. EPA (1990), representing data for 69 selected cities (U.S. Bureau of Census 1987; Baes, Sharp, Sjoreen and Shor 1984). The 69 selected cities are not identified; however, they appear to be located throughout the continental United States. U.S. EPA OSW recommends that site-specific data be used. The following uncertainty is associated with this variable: To the extent that a site is not located near an established meteorological data station, and site-specific data are not available, default average annual precipitation data may not accurately reflect site-specific conditions. As a result, *ksl* may be under- or overestimated. However, average annual precipitation data are reasonably available; therefore, uncertainty introduced by this variable is expected to be minimal.

TABLE B-1-5

COPC LOSS CONSTANT DUE TO LEACHING (SOIL INGESTION EQUATIONS)

Variable	Description	Units	Value
I	Average annual irrigation	cm/yr	**0 to 100** This variable is site-specific. This range is based on information presented in U.S. EPA (1990), representing data for 69 selected cities (Baes, Sharp, Sjoreen, and Shor 1984). The 69 selected cities are not identified; however, they appear to be located throughout the continental United States. The following uncertainty is associated with this variable: To the extent that site-specific or local average annual irrigation information is not available, default values (generally based on the closest comparable location) may not accurately reflect site-specific conditions. As a result, *ksl* may be under- or overestimated to an unknown degree.
RO	Average annual surface runoff from pervious areas	cm/yr	**Varies** This variable is site-specific. According to U.S. EPA (1993), U.S. EPA (1994b), and NC DEHNR (1997), average annual surface runoff can be estimated by using the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973). According to NC DEHNR (1997), this estimate can also be made by using more detailed, site-specific procedures, such as those based on the U.S. Soil Conservation Service CNE. U.S. EPA (1985) is cited as an example of such a procedure. The following uncertainty is associated with this variable: To the extent that site-specific or local average annual surface runoff information is not available, default or estimated values may not accurately represent site-specific or local conditions. As a result, *ksl* may be under- or overestimated to an unknown degree.
E_v	Average annual evapotranspiration	cm/yr	**35 to 100** This variable is site-specific. This range is based on information presented in U. S. EPA (1990), representing data from 69 selected cities. The 69 selected cities are not identified; however, they appear to be located throughout the continental United States. The following uncertainty is associated with this variable: To the extent that site-specific or local average annual evapotranspiration information is not available, default values may not accurately reflect site-specific conditions. As a result, *ksl* may be under- or overestimated to an unknown degree.

TABLE B-1-5

COPC LOSS CONSTANT DUE TO LEACHING
(SOIL INGESTION EQUATIONS)

Variable	Description	Units	Value
θ_{sw}	Soil volumetric water content	mL water/cm^3 soil	**0.2** This variable is site-specific, and depends on the available water and on soil structure; if a representative watershed soil can be identified, θ_{sw} can be estimated as the midpoint between a soil's field capacity and wilting point. U.S. EPA OSW recommends the use of 0.2 mL/cm^3 as a default value. This value is the midpoint of the range of 0.1 (very sandy soils) to 0.3 (heavy loam/clay soils) recommended by U.S. EPA (1993) (no source or reference is provided for this range) and is consistent with U.S. EPA (1994b) and NC DEHNR (1997). The following uncertainty is associated with this variable: The default θ_{sw} value may not accurately reflect site-specific or local conditions; therefore, *ksl* may be under- or overestimated to a small extent, based on the limited range of values.
Z_s	Soil mixing zone depth	cm	**1 to 20** U.S. EPA OSW recommends the following values for this variable: Soil / Depth (cm) / Reference Untilled / 1 / U.S. EPA (1990a) and U.S. EPA (1993a) Tilled / 20 / U.S. EPA (1990a) and U.S. EPA (1993a) U.S. EPA (1990) does not provide a reference for these values. U.S. EPA (1993c) cites U.S. EPA (1994a). Uncertainties associated with this variable include the following: (1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksl*. (2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksl*.

TABLE B-1-5

COPC LOSS CONSTANT DUE TO LEACHING (SOIL INGESTION EQUATIONS)

Variable	Description	Units	Value
BD	Soil bulk density	g soil/cm³ soil	**1.5** This variable is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil (Hillel 1980), as summarized in U.S. EPA (1990). A range of 0.83 to 1.84 was originally cited in Hoffman and Baes (1979). U.S. EPA (1994b) recommended a default soil bulk density value of 1.5 g/cm³, based on a mean value for loam soil from Carsel, Parrish, Jones, Hansen, and Lamb (1988). The value of 1.5 g/cm³ also represents the midpoint of the "relatively narrow range" for *BD* of 1.2 to 1.7 g/cm³ (U.S. EPA 1993). The following uncertainty is associated with this variable: The recommended soil bulk density value may not accurately represent site-specific soil conditions.
Kd_s	Soil-water partition coefficient	cm³ water/g soil	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Uncertainties associated with this parameter will be limited if Kd_s values are calculated as described in Appendix A-3.

REFERENCES AND DISCUSSION

Baes, C.F., R.D. Sharp, A.L. Sjoreen and R.W. Shor. 1984. "A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture." Prepared for the U.S. Department of Energy under Contract No. DEAC05-840R21400.

For the continental United States, as cited in U.S. EPA (1990), this document is the source of a series of maps showing: (1) average annual precipitation (*P*), (2) average annual irrigation (*I*), and (3) average annual evapotranspiration isolines.

Carsel, R.F., R.S. Parrish, R.L. Jones, J.L. Hansen, and R.L. Lamb. 1988. "Characterizing the Uncertainty of Pesticide Leaching in Agricultural Soils." *Journal of Contaminant Hydrology.* Vol. 2. Pages 11-24.

This document is cited by U.S. EPA (1994b) as the source for a mean soil bulk density value, *BD*, of 1.5 g soil/cm^3 soil for loam soil.

Geraghty, J.J., D.W. Miller, F. Van der Leeden, and F.L. Troise. 1973. *Water Atlas of the United States.* Water Information Center, Port Washington, New York.

This document is cited by U.S. EPA (1993), U.S. EPA (1994b), and NC DEHNR (1997) as a reference for calculating average annual runoff, *RO*. This document provides maps with isolines of annual average surface runoff, which is defined as all flow contributions to surface water bodies, including direct runoff, shallow interflow, and ground water recharge. Because these volumes are total contributions and not only surface runoff, U.S. EPA (1994b) recommends that the volumes be reduced by 50 percent in order to estimate average annual surface runoff.

This document presents a soil bulk density, *BD*, range of 0.83 to 1.84.

Hillel, D. 1980. *Fundamentals of Soil Physics.* Academic Press, Inc. New York, New York.

This document is cited by U.S. EPA (1990) for the statement that soil bulk density, *BD*, is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil.

Hoffman, F.O., and C.F. Baes. 1979. *A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides.* ORNL/NUREG/TM-882.

This document presents a soil bulk density, *BD*, range of 0.83 to 1.84.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is one of the source documents that cites the use of the equation in Table B-1-5. However, the document is not the original source of this equation. This document also recommends the following:

- Estimation of average annual surface runoff, *RO* (cm/yr), by using the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973) or site-specific procedures, such as using the U.S. Soil Conservation Service CNE; U.S. EPA 1985 is cited as an example of such a procedure.
- A default value of 0.2 (mL water/cm^3 soil) for soil volumetric water content, θ_{sw}

U.S. Bureau of the Census. 1987. *Statistical Abstract of the United States:* 1987. 107th edition. Washington, D.C.

This document is a source of average annual precipitation (*P*) information for 69 selected cites, as cited in U.S. EPA (1990); these 69 cities are not identified.

U.S. EPA. 1985. *Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Groundwater.* Part I (Revised 1985). Environmental Research Laboratory. Athens, Georgia. EPA/600/6-85/002a. September.

This document is cited by NC DEHNR (1997) as an example of the use of the U.S. Soil Conservation Service CNE to estimate *RO*.

U.S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600-90-003. January.

This document presents ranges of (1) average annual precipitation, (2) average annual irrigation, and (3) average annual evapotranspiration. This document cites Baes, Sharp, Sjoreen, and Shor (1984) and U.S. Bureau of the Census (1987) as the original sources of this information.

U.S. EPA. 1993. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, D.C. November.

This document is one of the reference sources for the equation in Table B-1-5; this document also recommends the following:

- A range of soil volumetric water content, θ_{sw}, values of 0.1 (very sandy soils) to 0.3 (heavy loam/clay soils); the original source or reference for these values is not identified.
- A range of values for soil mixing depth, Z_s, for tilled and untilled soil; the original source reference for these values is not identified.
- A range (2 to 280,000 [mL water/g soil]) of Kd_s values for inorganic COPCs
- A "relatively narrow range" for soil bulk density, *BD*, of 1.2 to 1.7 (g soil/cm^3 soil)

This document is one of the reference source documents for the equation in Table B-1-5. The original source of this equation is not identified. This document also presents a range of values for soil mixing depth, *Z*, for tilled and untilled soil; the original source of these values is not identified. Finally, this document presents several COPC-specific Kd_s values that were used to establish a range (2 to 280,000 [mL water/g soil]) of Kd_s values.

U.S. EPA. 1994a. *Estimating Exposure to Dioxin-Like Compounds. Volume III: Site-specific Assessment Procedures.* External Review Draft. Office of Research and Development. Washington, D.C. EPA/600/6-88/005Cc. June.

This document presents values for soil mixing depth, Z_s, for tilled and untilled soil, as cited in U.S. EPA (1993).

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document recommends (1) a default soil volumetric water content, θ_{sw}, value of 0.2 (mL water/cm^3 soil), based on U.S. EPA (1993), and (2) a default soil bulk density, *BD*, value of 1.5 (g soil/cm^3 soil), based on a mean value for loam soil from Carsel, Parrish, Jones, Hansen, and Lamb (1988).

TABLE B-1-6

COPC LOSS CONSTANT DUE TO VOLATILIZATION
(SOIL INGESTION EQUATIONS)

Description

This equation calculates the COPC loss constant from soil due to volatilization. Consistent with U.S. EPA guidance (1994) and based on the need for additional research to be conducted to determine the magnitude of the uncertainty introduced for modeling volatile COPCs from soil, U.S. EPA OSW recommends that, until identification and validation of more applicable models, the constant for the loss of soil resulting from volatilization (*ksv*) should be set equal to zero. In cases where high concentrations of volatile organic compounds are expected to be present in the soil and the permitting authority considers calculation of *ksv* to be appropriate, the equation presented in this table should be considered. U.S. EPA OSW also recommends consulting the methodologies described in U.S. EPA NCEA document, *Methodology for Assessing Health Risks Associated with Multiple Exposure Pathways to Combustor Emissions* (In Press). Uncertainties associated with this equation include the following:

(1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksv*.

(2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksv*.

Equation

$$ksv = \left[\frac{3.1536 \cdot 10^{7} \cdot H}{Z_s \cdot Kd_s \cdot R \cdot T_a \cdot BD}\right] \cdot \left[0.482 \cdot W^{0.78} \cdot \left(\frac{\mu_a}{\rho_a \cdot D_a}\right)^{-0.67} \cdot \left(\sqrt{\frac{4A}{\pi}}\right)^{-0.11}\right]$$

Variable	Definition	Units	Value
ksv	COPC loss constant due to volatilization	yr^{-1}	**0** Consistent with U.S. EPA guidance (1994) and based on the need for additional research to be conducted to determine the magnitude of the uncertainty introduced for modeling volatile COPCs from soil, U.S. EPA OSW recommends that, until identification and validation of more applicable models, the constant for the loss of soil resulting from volatilization (*ksv*) should be set equal to zero.
0.482	Empirical constant	unitless	This is an empirical constant calculated during the development of this equation.
0.78	Empirical constant	unitless	This is an empirical constant calculated during the development of this equation.
-0.67	Empirical constant	unitless	This is an empirical constant calculated during the development of this equation.
-0.11	Empirical constant	unitless	This is an empirical constant calculated during the development of this equation.
$3.1536 \times 10^{+07}$	Units conversion factor	s/yr	

Variable	Definition	Units	Value
H	Henry's Law constant	atm-m^3/mol	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Values for this variable, estimated by using the parameters and algorithms in Appendix A-3, may under- or overestimate the actual COPC-specific values. As a result, *ksv* may be under- or overestimated.
Z_s	Soil mixing zone depth	cm	**1 to 20** U.S. EPA OSW recommends the following values for this variable: Soil / Depth (cm) / Reference Untilled / 1 / U.S. EPA (1990a) and U.S. EPA (1993a) Tilled / 20 / U.S. EPA (1990a) and U.S. EPA (1993a) U.S. EPA (1990) does not provide a reference for these values. U.S. EPA (1993a) cites U.S. EPA (1994a). Uncertainties associated with this variable include the following: (1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksr*. (2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksv*.
Kd_s	Soil-water partition coefficient	cm^3 water/g soil	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Uncertainties associated with this parameter will be limited if Kd_s values are calculated as described in Appendix A-3.
R	Universal gas constant	atm-m^3/mol-K	**8.205 x 10^{-5}** There are no uncertainties associated with this parameter.

TABLE B-1-6

COPC LOSS CONSTANT DUE TO VOLATILIZATION (SOIL INGESTION EQUATIONS)

Variable	Definition	Units	Value
T_a	Ambient air temperature	K	**298** This variable is site-specific. U.S. EPA (1990) also recommends an ambient air temperature of 298 K. The following uncertainty is associated with this variable: To the extent that site-specific or local values for the variable are not available, default values may not accurately represent site-specific conditions. The uncertainty associated with the selection of a single value from within the temperature range at a single location is expected to be more significant than the uncertainty associated with choosing a single ambient temperature to represent all localities.
BD	Soil bulk density	g soil/cm^3 soil	**1.5** This variable is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil (Hillel 1980), as summarized in U.S. EPA (1990). A range of 0.83 to 1.84 was originally cited in Hoffman and Baes (1979). U.S. EPA (1994b) recommended a default soil bulk density value of 1.5 g/cm^3, based on a mean value for loam soil from Carsel, Parrish, Jones, Hansen, and Lamb (1988). The value of 1.5 g/cm^3 also represents the midpoint of the "relatively narrow range" for *BD* of 1.2 to 1.7 g/cm^3 (U.S. EPA 1993). The following uncertainty is associated with this variable: The recommended soil bulk density value may not accurately represent site-specific soil conditions.
W	Average annual wind speed	m/s	**3.9** Consistent with U.S. EPA (1990), U.S. EPA OSW recommends a default value of 3.9 m/s. See Chapter 3 for guidance regarding the references and methods used to determine a site-specific value that is consistent with air dispersion modeling. The following uncertainty is associated with this variable: To the extent that site-specific or local values for this variable are not available, default values may not accurately represent site-specific conditions. The uncertainty associated with the selection of a single value from within the range of windspeeds at a single location may be more significant than the uncertainty associated with choosing a single windspeed to represent all locations.

TABLE B-1-6

COPC LOSS CONSTANT DUE TO VOLATILIZATION (SOIL INGESTION EQUATIONS)

Variable	Definition	Units	Value
μ_a	Viscosity of air	g/cm-s	**1.81×10^{-04}** U.S. EPA OSW recommends the use of this value, based on Weast (1980). This value applies at standard conditions (20°C or 298 K and 1 atm or 760 mm Hg). The viscosity of air may vary slightly with temperature.
ρ_a	Density of air	g/cm^3	**0.0012** U.S. EPA OSW recommends the use of this value, based on Weast (1980). This value applies at standard conditions (20°C or 298 K and 1 atm or 760 mm Hg). The density of air will vary with temperature.
D_a	Diffusivity of COPC in air	cm^2/s	**Varies** This value is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: The default D_a values may not accurately represent the behavior of COPCs under site-specific conditions. However, the degree of uncertainty is expected to be minimal.
A	Surface area of contaminated area	m^2	**1.0** See Chapter 5 for guidance regarding the calculation of this value.

COPC LOSS CONSTANT DUE TO VOLATILIZATION (SOIL INGESTION EQUATIONS)

REFERENCES AND DISCUSSION

Carsel, R.F., R.S, Parrish, R.L. Jones, J.L. Hansen, and R.L. Lamb. 1988. "Characterizing the Uncertainty of Pesticide Leaching in Agricultural Soils." *Journal of Contaminant Hydrology*. Vol. 2. Pages 11-24.

This document is cited by U.S. EPA (1994b) as the source of a mean soil bulk density value, *BD*, of 1.5 (g soil/cm^3 soil) for loam soil.

Hillel, D. 1980. *Fundamentals of Soil Physics*. Academic Press, Inc. New York, New York.

Hoffman, F.O., and C.F. Baes. 1979. *A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides*. ORNL/NUREG/TM-882.

This document presents a soil bulk density, *BD*, range of 0.83 to 1.84.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units*. January.

This document is one of the source documents that cites the use of the equation in Table B-1-6.

U. S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions*. Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600-90-003. January.

This document recommends the following:

- A range of values for soil mixing zone depth, Z_s, for tilled and untilled soil; however, the source or basis for these values is not identified
- A default ambient air temperature of 298 K
- An average annual wind speed of 3.9 m/s; however, no source or reference for this value is identified.

U.S. EPA. 1993. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions*. External Review Draft. Office of Research and Development. Washington, D.C. November.

This document is one of the reference source documents for the equation in Table B-1-6; however, the original reference for this equation is not identified.

This document also presents the following:

- A range of values for soil mixing depth, Z_s, for tilled and untilled soil; however, the original source of these values is not identified.
- COPC-specific Kd_s values that were used to establish a range (2 to 280,000 [mL water/g soil]) of Kd_s values for inorganic COPCs
- A "relatively narrow range" for soil bulk density, *BD*, of 1.2 to 1.7 (g soil/cm^3 soil)

U.S. EPA. 1994. *Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities*. April 15.

U.S. EPA. 1994a. *Estimating Exposure to Dioxin-Like Compounds. Volume III: Site-specific Assessment Procedures* External Review Draft. Office of Research and Development. Washington, D.C. EPA/600/6-88/005Cc. June.

This document presents value for soil, mixing depth, Z_s, for tilled and untilled soil as cited in U.S. EPA (1993).

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Waste. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document recommends a default soil density, *BD*, value of 1.5 (g soil/cm^3 soil), based on a mean value for loam soil that is taken from Carsel, Parrish, Jones, Hansen, and Lamb (1988).

Weast, R.C. 1980. *Handbook of Chemistry and Physics.* 61st Edition. CRC Press, Inc. Cleveland, Ohio.

This document is cited by NC DEHNR (1997) as the source recommended values for viscosity of air, μ_a, and density of air, ρ_a.

TABLE B-2-1

SOIL CONCENTRATION DUE TO DEPOSITION (CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Description
The equations in this table are used to calculate an average COPC soil concentration resulting from wet and dry deposition of particles and vapors to soil over the exposure duration. COPCs are assumed to be incorporated only to a finite depth (the soil mixing zone depth, Z_s). The COPC soil concentration averaged over the exposure duration, represented by *Cs*, should be used for carcinogenic COPCs, where the risk is averaged over the lifetime of an individual. Because the hazard quotient associated with noncarcinogenic COPCs is based on a reference dose rather than a lifetime exposure, the highest annual average COPC soil concentration occurring during the exposure duration period should be used for noncarcinogenic COPCs. The highest annual average COPC soil concentration would occur at the end of the time period of combustion and is represented by Cs_{tD}. The following uncertainties are associated with this variable: (1) The time period for deposition of COPCs resulting from hazardous waste combustion is assumed to be a conservative, long-term value. This assumption may overestimate *Cs* and Cs_{tD}. (2) Exposure duration values (T_2) are based on historical mobility studies and will not necessarily remain constant. Specifically, mobility studies indicate that most receptors that move remain in the vicinity of the combustion unit; however, it is impossible to accurately predict the probability that these short-distance moves will influence exposure, based on factors such as atmospheric transport of pollutants. (3) The use of a value of zero for T_1 does not account for exposure that may have occurred from historic operations and emissions from hazardous waste combustion. This may underestimate *Cs* and Cs_{tD}. (4) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils and, resulting a greater mixing depth. This uncertainty may overestimate *Cs* and Cs_{tD}. (5) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *Cs* and Cs_{tD}.

TABLE B-2-1

SOIL CONCENTRATION DUE TO DEPOSITION
(CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Equation for Carcinogens

Soil Concentration Averaged Over Exposure Duration

$$Cs = \frac{\left(\frac{Ds \cdot tD - Cs_{tD}}{ks}\right) + \left(\frac{Cs_{tD}}{ks} \cdot [1 - \exp(-ks\,(T_2 - tD))]\right)}{(T_2 - T_1)} \quad for\ T_1 < tD < T_2$$

$$Cs = \frac{Ds}{ks \cdot (tD - T_1)} \cdot \left(\left[tD + \frac{\exp(-ks \cdot tD)}{ks} \right] - \left[T_1 + \frac{\exp(-ks \cdot T_1)}{ks} \right] \right) \quad for\ T_2 \leq tD$$

Equation for Noncarcinogens

Highest Annual Average Soil Concentration

$$Cs_{tD} = \frac{Ds \cdot [1 - \exp(-ks \cdot tD)]}{ks}$$

where

$$Ds = \frac{100 \cdot Q}{Z_s \cdot BD} \cdot [F_v\ (0.31536 \cdot Vdv \cdot Cyv + Dywv) + (Dydp + Dywp) \cdot (1 - F_v)]$$

For mercury modeling

$$Ds = \frac{100 \cdot (0.48Q)}{Z_s \cdot BD} \cdot [F_v\ (0.31536 \cdot Vdv \cdot Cyv + Dywv) + (Dydp + Dywp) \cdot (1 - F_v)]$$

Use *0.48Q* for total mercury and $F_v = 0.85$ in the mercury modeling equation to calculate *Ds*. The calculated *Ds* value is apportioned into the divalent mercury (Hg^{2+}) and methyl mercury (MHg) forms based on the assumed 98% Hg^{2+} and 2% MHg speciation split in soils (see Chapter 2). Elemental mercury (Hg^0) occurs in very small amounts in the vapor phase and does not exist in the particle or particle-bound phase. Therefore, elemental mercury deposition onto soils is assumed to be negligible or zero. Elemental mercury is evaluated for the direct inhalation pathway only (Table B-5-1).

Ds (Hg^{2+})	=	0.98 *Ds*
Ds (Mhg)	=	0.02 *Ds*
Ds (Hg^0)	=	0.0

Evaluate divalent and methyl mercury as individual COPCs. Calculate *Cs* for divalent and methyl mercury using the corresponding (1) fate and transport parameters for mercuric chloride (divalent mercury) and methyl mercury provided in Appendix A-3, and (2) *Ds* (Hg^{2+}) and *Ds* (MHg) as calculated above.

TABLE B-2-1

SOIL CONCENTRATION DUE TO DEPOSITION (CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Variable	Description	Units	Value
Cs	Average soil concentration over exposure duration	mg COPC/kg soil	
Cs_{tD}	Soil concentration at time *tD*	mg COPC/kg soil	
Ds	Deposition term	mg COPC/kg soil-yr	**Varies** U.S. EPA (1994a) and NC DEHNR (1991) recommend incorporating the use of a deposition term into the *Cs* equation. Uncertainties associated with this variable include the following: (1) Five of the variables in the equation for *Ds* (*Q, Cyv, Dywv, Dywp,* and *Dydp*) are COPC- and site-specific. Values of these variables are estimated on the basis of modeling. The direction and magnitude of any uncertainties should not be generalized. (2) Based on the narrow recommended ranges, uncertainties associated with *Vdv*, F_v, and *BD* are expected to be low. (3) Values for Z_s vary by about one order of magnitude. Uncertainty is greatly reduced if it is known whether soils are tilled or untilled.
tD	Time period over which deposition occurs (time period of combustion)	yr	**100** U.S. EPA (1990a) specifies that this period of time can be represented by periods of 30, 60 or 100 years. U.S. EPA OSW recommends that facilities use the conservative value of 100 years unless site-specific information is available indicating that this assumption is unreasonable (see Chapter 6 of the HHRAP Protocol).
ks	COPC soil loss constant due to all processes	yr^{-1}	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-2-2. The COPC soil loss constant is the sum of all COPC removal processes. Uncertainty associated with this variable includes the following: COPC-specific values for *ksg* (one of the variables in the equation in Table B-2-2) are empirically determined from field studies. No information is available regarding the application of these values to the site-specific conditions associated with affected facilities.

Variable	Description	Units	Value
T_2	Length of exposure duration	yr	**6, 30, or 40** U.S. EPA OSW recommends the following reasonable maximum exposure (RME) values for T_2: Exposure Duration / RME / Reference Child Resident, Subsistence Farmer Child, Subsistence Fisher Child / 6 years / U.S. EPA (1990b) Adult Resident and Subsistence Fisher / 30 years (6 child and 24 adult) / U.S. EPA (1990b) Subsistence Farmer / 40 years / U.S. EPA (1994b) U.S. EPA (1994c) recommended the following unreferenced values: Exposure Duration / Years Subsistence Farmer / 40 Adult Resident / 30 Subsistence Fisher / 30 Child Resident / 9 Uncertainties associated with this variable include the following: (1) Exposure duration rates are based on historical mobility rates and may not remain constant. This assumption may overestimate or underestimate *Cs* and Cs_{tD}. (2) Mobility studies indicate that most receptors that move remain in the vicinity of the emission sources; however, it is impossible to accurately predict the likelihood that these short-distance moves will influence exposure, based on factors such as atmospheric transport of pollutants. This assumption may overestimate or underestimate *Cs* and Cs_{tD}.
T_1	Time period at the beginning of combustion	yr	**0** Consistent with U.S. EPA (1994bc), U.S. EPA OSW recommends a value of 0 for T_1. The following uncertainty is associated with this variable: The use of a value of 0 for T_1 does not account for exposure that may have occurred from historical operation or emissions from the combustion of hazardous waste. This may underestimate *Cs* and Cs_{tD}.

Variable	Description	Units	Value
100	Units conversion factor	mg-cm²/kg-cm²	
Q	COPC emission rate	g/s	**Varies** This variable is COPC- and site-specific. See Chapters 2 and 3 of the HHRAP for guidance regarding the calculation of this variable.
Z_s	Soil mixing zone depth	cm	**1 to 20** U.S. EPA OSW recommends the following values for this variable: Soil / Depth (cm) / Reference Untilled / 1 / U.S. EPA (1990a) and U.S. EPA (1993a) Tilled / 20 / U.S. EPA (1990a) and U.S. EPA (1993a) U.S. EPA (1990a) does not include a reference for these values. The following uncertainties are associated with this variable: (1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting a greater mixing depth. This uncertainty may overestimate *Cs* and Cs_{tD}. (2) Deposition to hard surfaces may result in dust residues that have negligible dilution in comparison to that of other residues. This uncertainty may underestimate *Cs* and Cs_{tD}.
BD	Soil bulk density	g soil/cm³ soil	**1.5** This variable is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil (Hillel 1980), as summarized in U.S. EPA (1990a). A range of 0.83 to 1.84 was originally cited in Hoffman and Baes (1979). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g/cm³, based on a mean value for loam soil that was obtained from Carsel, Parrish, Jones, Hansen, and Lamb (1988). The value of 1.5 g/cm³ also represents the midpoint of the "relatively narrow range" for *BD* of 1.2 to 1.7 g/cm³ (U.S. EPA 1993a). The following uncertainty is associated with this variable: The recommended *BD* value may not accurately represent site-specific soil conditions; and may under- or overestimate site-specific soil conditions to an unknown degree.

Variable	Description	Units	Value
F_v	Fraction of COPC air concentration in vapor phase	unitless	**0 to 1** This variable is COPC-specific. Discussion of this variable and COPC-specific values are presented in Appendix A-3. This range is based on the values presented in Appendix A-3. Values are also presented in U.S. EPA (1994c) and NC DEHNR (1997). F_v was calculated using an equation presented in Junge (1977) for all organic COPCs, including PCDDs and PCDFs. U.S. EPA (1994c) states that $F_v = 0$ for all metals (except mercury). The following uncertainties are associated with this variable: (1) It is based on the assumption of a default S_T value for background plus local sources, rather than an S_T value for urban sources. If a specific site is located in an urban area, the use of the latter S_T value may be more appropriate. Specifically, the S_T value for urban sources is about one order of magnitude greater than that for background plus local sources, and it would result in a lower calculated F_v value; however, the F_v value is likely to be only a few percent lower. (2) According to Bidleman (1988), the equation used to calculate F_v assumes that the variable *c* (Junge constant) is constant for all chemicals; however, the value of *c* depends on the chemical (sorbate) molecular weight, the surface concentration for monolayer coverage, and the difference between the heat of desorption from the particle surface and the heat of vaporization of the liquid phase sorbate. To the extent that site- or COPC-specific conditions may cause the value of *c* to vary, uncertainty is introduced if a constant value of *c* is used to calculate F_v.
0.31536	Units conversion factor	m-g-s/cm-µg-yr	
Vdv	Dry deposition velocity	cm/s	**3** U.S. EPA (1994c) recommended the use of 3 cm/s for the dry deposition velocity, based on median dry deposition velocity for HNO_3 from an unspecified U.S. EPA database of dry deposition velocities for HNO_3, ozone, and SO_2. HNO_3 was considered the most similar to the COPCs recommended for consideration in the HHRAP. The value should be applicable to any organic COPC with a low Henry's Law Constant. The following uncertainty is associated with this variable: HNO_3 may not adequately represent specific COPCs; therefore, the use of a single value may under- or overestimate estimated soil concentration.
Cyv	Unitized yearly average air concentration from vapor phase	µg-s/g-m³	**Varies** This variable is COPC- and site-specific, and is determined by air modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.

TABLE B-2-1

SOIL CONCENTRATION DUE TO DEPOSITION (CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Variable	Description	Units	Value
Dywv	Unitized yearly average wet deposition from vapor phase	s/m^2-yr	**Varies** This variable is COPC- and site-specific, and is determined by air modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.
Dydp	Unitized yearly average dry deposition from particle phase	s/m^2-yr	**Varies** This variable is COPC- and site-specific, and is determined by air modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.
Dywp	Unitized yearly average wet deposition from particle phase	s/m^2-yr	**Varies** This variable is COPC- and site-specific, and is determined by air modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.

REFERENCES AND DISCUSSION

Bidleman, T.F. 1988. "Atmospheric Processes." *Environmental Science and Technology.* Volume 22. Number 4. Pages 361-367.

This reference is for the statement that the equation used to calculate the fraction of air concentration in vapor phase (F_v) assumes that the variable *c* (the Junge constant) is constant for all chemicals. However, this document notes that the value of *c* depends on the chemical (sorbate) molecular weight, the surface concentration for monolayer coverage, and the difference between the heat of desorption from the particle surface and the heat of vaporization of the liquid-phase sorbate. The following equation, presented in this document, is cited by U.S. EPA (1994b) and NC DEHNR (1997) for calculating the variable F_v:

$$F_v = 1 - \frac{c \cdot S_T}{P^\circ_L + c \cdot S_T}$$

where

F_v = Fraction in vapor phase (unitless)
c = Junge constant = 1.7 x 10^{-04} (atm-cm)
S_T = Whitby's average surface area of particulates = 3.5 x 10^{-06} cm^2/cm^3 air (corresponds to background plus local sources)
P°_L = Liquid-phase vapor pressure of chemical (atm) (see Appendix A-3)

If the chemical is a solid at ambient temperatures, the solid phase vapor pressure is converted to a liquid-phase vapor pressure as follows:

$$\ln \frac{P^\circ_L}{P^\circ_S} = \frac{\Delta S_f}{R} \cdot \frac{(T_m - T_a)}{T_a}$$

where

P°_S = Solid-phase vapor pressure of chemical (atm) (see Appendix A-3)
$\frac{\Delta S_f}{R}$ = Entropy of fusion over the universal gas constant = 6.79 (unitless)
T_m = Melting point of chemical (K) (see Appendix A-3)
T_a = Ambient air temperature = 284 K (11°C)

Carsel, R.F., R.S. Parrish, R.L. Jones, J.L. Hansen, and R.L. Lamb. 1988. "Characterizing the Uncertainty of Pesticide Leaching in Agricultural Soils." *Journal of Contaminant Hydrology*. Vol. 2. Pages 11-24.

This reference is cited by U.S. EPA (1994b) as the source for a mean soil bulk density value, *BD*, of 1.5 (g soil/cm^3 soil) for loam soil.

Hillel, D. 1980. *Fundamentals of Soil Physics*. Academic Press, Inc. New York.

This document is cited by U.S. EPA (1990a) for the statement that soil bulk density, *BD*, is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil.

Hoffman, F.O., and C.F. Baes, 1979. *A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides.* ORNL/NOREG/TM-882.

This document presents a soil bulk density range, *BD*, of 0.83 to 1.84.

Junge, C.E. 1977. *Fate of Pollutants in Air and Water Environments, Part I.* Suffet, I.H., Ed. Wiley. New York. Pages 7-26.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This is one of the source documents for the equation in Table B-1-1. This document also recommends the use of (1) a deposition term, *Ds*, and (2) COPC-specific F_v (fraction of COPC air concentration in vapor phase) values.

Research Triangle Institute (RTI). 1992. *Preliminary Soil Action Level for Superfund Sites.* Draft Interim Report. Prepared for U.S. EPA Hazardous Site Control Division, Remedial Operations Guidance Branch. Arlington, Virginia. EPA Contract 68-W1-0021. Work Assignment No. B-03, Work Assignment Manager Loren Henning. December.

This document is a reference source for COPC-specific F_v (fraction of COPC air concentration in vapor phase) values.

U.S. EPA. 1990a. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600-90-003. January.

This document is a reference source for the equation in Table B-2-1, and it recommends that (1) the time period over which deposition occurs (time period for combustion), *tD*, be represented by periods of 30, 60 and 100 years, and (2) undocumented values for soil mixing zone depth, Z_s, for tilled and untilled soil.

U.S. EPA. 1990b. *Exposure Factors Handbook.* March.

This document is a reference source for values for length of exposure duration, T_2.

U.S. EPA. 1992. *Estimating Exposure to Dioxin-Like Compounds.* Draft. Office of Research and Development. Washington, D.C. EPA/600/6-88/005b.

This document is cited by U.S. EPA (1993a) as the source of values for soil mixing zone depth, Z_s, for tilled and untilled soils.

U.S. EPA. 1993a. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, D.C. November.

This document is a reference for recommended values for soil mixing zone depth, Z_s, for tilled and untilled soils; it cites U.S. EPA (1992) as the source of these values. It also recommends a "relatively narrow" range for soil bulk density, *BD*, of 1.2 to 1.7 (g soil/cm^3 soil).

U.S. EPA. 1993b. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Working Group Recommendations. Office of Solid Waste. Office of Research and Development. Washington, D.C. September 24.

This document is a reference for the equation in Table B-2-1. It recommends using a deposition term, *Ds*, and COPC-specific F_v values (fraction of COPC air concentration in vapor phase) in the *Cs* equation.

U.S. EPA. 1994a. *Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. April 15.

This document is a reference for the equation in Table B-2-1; it recommends that the following be used in the *Cs* equation: (1) a deposition term, *Ds*, and (2) a default soil bulk density value of 1.5 g/cm^3, based on a mean value for loam soil from Carsel, Parrish, Jones, Hansen, and Lamb (1988).

U.S. EPA. 1994b. *Estimating Exposure to Dioxin-Like Compounds. Volume III: Site-Specific Assessment Procedures.* External Review Draft. Office of Research and Development. Washington, D.C. EPA/600/6-88/005Cc. June.

This document recommends values for length of exposure duration, T_2, for the subsistence farmer.

U.S. EPA. 1994c. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

The value for dry deposition velocity is based on median dry deposition velocity for HNO_3 from a U.S. EPA database of dry deposition velocities for HNO3 ozone, and SO_2. HNO_3 was considered the most similar to the constituents covered and the value should be applicable to any organic compound having a low Henry's Law Constant. The reference document for this recommendation was not cited. This document recommends the following:

- Values for the length of exposure duration, T_2
- Value of 0 for the time period of the beginning of combustion, T_1
- F_v values (fraction of COPC air concentration in vapor phase) that range from 0.27 to 1 for organic COPCs
- *Vdv* value (dry deposition velocity) of 3 cm/s (however, no reference is provided for this recommendation)
- Default soil bulk density value of 1.5 g/cm^3, based on a mean for loam soil from Carsel, Parrish, Jones, Hansen, and Lamb (1988)
- *Vdv* value of 3 cm/s, based on median dry deposition velocity for HNO_3 from an unspecified U.S. EPA database of dry deposition velocities for HNO_3, ozone, and SO_2. HNO_3 was considered the most similar to the COPCs recommended for consideration in the HHRAP.

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

TABLE B-2-2

COPC SOIL LOSS CONSTANT
(CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Description

This equation calculates the COPC soil loss constant, which accounts for the loss of COPCs from soil by several mechanisms.

Uncertainties associated with this equation include the following:

(1) COPC-specific values for *ksg* are empirically determined from field studies; no information is available regarding the application of these values to the site-specific conditions associated with affected facilities.
(2) The source of the equations in Tables B-2-3 through B-2-6 have not been identified.

Equation

$$ks = ksg + kse + ksr + ksl + ksv$$

Variable	Description	Units	Value
ks	COPC soil loss constant due to all processes	yr^{-1}	
ksg	COPC loss constant due to biotic and abiotic degradation	yr^{-1}	**Varies** This variable is COPC-specific and should be determined from the COPC in Appendix A-3. "Degradation rate" values are also presented in NC DEHNR (1997); however, no reference or source is provided for the values. U.S. EPA (1994a) and U.S. EPA (1994b) state that *ksg* values are COPC-specific; however, all *ksg* values are presented as zero (U.S. EPA 1994a) or as "NA" (U.S. EPA 1994b); the basis of these assumptions is not addressed. The following uncertainty is associated with this variable: COPC-specific values for *ksg* are empirically determined from field studies; no information is available regarding the application of these values to the site-specific conditions associated with affected facilities.

TABLE B-2-2

COPC SOIL LOSS CONSTANT
(CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Variable	Description	Units	Value
kse	COPC loss constant due to soil erosion	yr^{-1}	**0** This variable is COPC- and site-specific, and is further discussed in Table B-2-3. Consistent with U.S. EPA (1994a), U.S. EPA (1994b) and NC DEHNR (1997), U.S. EPA OSW recommends that the default value assumed for *kse* is zero because of contaminated soil eroding onto the site and away from the site. Uncertainties associated with this variable include the following: (1) The source of the equation in Table B-2-3 has not been identified. (2) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting a greater mixing depth. This uncertainty may overestimate *kse*. (3) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *kse*.
ksr	COPC loss constant due to surface runoff	yr^{-1}	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-2-4. No reference document is cited for this equation. The use of this equation is consistent with U.S. EPA (1994b) and NC DEHNR (1997). U.S. EPA (1994a) states that all *ksr* values are zero but does not explain the basis of this assumption. Uncertainties associated with this variable (calculated by using the equation in Table B-2-4) include the following: (1) The source of the equation in Table B-2-4 has not been identified. (2) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksr*. (3) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksr*.
ksl	COPC loss constant due to leaching	yr^{-1}	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-2-5. The use of this equation is consistent with U.S. EPA (1993), U.S. EPA (1994b), and NC DEHNR (1997). U.S. EPA (1994a) states that all *ksl* values are zero but does not explain the basis of this assumption. Uncertainties associated with this variable (calculated by using the equation in Table B-2-5) include the following: (1) The source of the equation in Table B-2-5 has not been identified. (2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksl*.

TABLE B-2-2

COPC SOIL LOSS CONSTANT
(CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Variable	Description	Units	Value
ksv	COPC loss constant due to volatilization	yr^{-1}	**0** This variable is COPC- and site-specific, and is further discussed in Table B-2-6. Consistent with U.S. EPA guidance (1994a) and based on the need for additional research to be conducted to determine the magnitude of the uncertainty introduced for modeling volatile COPCs from soil, U.S. EPA OSW recommends that, until identification and validation of more applicable models, the constant for the loss of soil resulting from volatilization (*ksv)* should be set equal to zero. Uncertainties associated with this variable include the following: (1) The source of the equation in Table B-2-6 has not been identified. (2) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting a greater mixing depth. This uncertainty may overestimate *ksv*. (3) Deposition to hard surfaces may result in dust residues that have negligible dilution, (as a result of potential mixing with in-situ materials) in comparison to that of other residues. This uncertainty may underestimate *ksv*.

TABLE B-2-2

COPC SOIL LOSS CONSTANT
(CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

REFERENCES AND DISCUSSION

NC DEHNR. 1997. *Final NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is one of the reference documents for the equations in Tables B-2-4, B-2-5, and B-2-6. This document is also cited as (1) the source for a range of COPC-specific degradation rates (*ksg*), and (2) one of the sources that recommend using the assumption that the loss resulting from erosion (*kse*) is zero because of contaminated soil eroding onto the site and away from the site.

U.S. EPA. 1993. *Review Draft Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Office of Health and Environmental Assessment. Office of Research and Development. EPA-600-AP-93-003. November 10.

This document is one of the reference documents for the equations in Tables B-2-3 and B-2-5.

U.S. EPA. 1994a. *Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* April 15.

This document is cited as a source for the assumptions that losses resulting from erosion (*kse*), surface runoff (*ksr*), degradation (*ksg*), leaching (*ksl*), and volatilization (*ksv*) are all zero.

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document is one of the reference documents for the equations in Tables B-2-4, B-2-5, and B-2-6. This document is also cited as one of the sources that recommend using the assumption that the loss resulting from erosion (*kse*) is zero and the loss resulting from degradation (*ksg*) is "NA" or zero for all compounds.

COPC LOSS CONSTANT DUE TO SOIL EROSION (CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Description

This equation calculates the constant for COPC loss resulting from erosion of soil. Consistent with U.S. EPA (1994), U.S. EPA (1994b), and NC DEHNR (1997), U.S. EPA OSW recommends that the default value assumed for *kse* is zero because of contaminated soil eroding onto the site and away from the site. In site-specific cases where the permitting authority considers it appropriate to calculate a *kse*, the following equation presented in this table should be considered along with associated uncertainties. Additional discussion on the determination of *kse* can be obtained from review of the methodologies described in U.S. EPA NCEA document, *Methodology for Assessing Health Risks Associated with Multiple Exposure Pathways to Combustor Emissions* (In Press). Uncertainties associated with this equation include:

(1) For soluble COPCs, leaching might lead to movement below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *kse*.
(2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *kse*.

Equation

$$kse = \frac{0.1 \cdot X_e \cdot SD \cdot ER}{BD \cdot Z_s} \cdot \left(\frac{Kd_s \cdot BD}{\theta_{sw} + (Kd_s \cdot BD)} \right)$$

Variable	Description	Units	Value
kse	COPC loss constant due to soil erosion	yr^{-1}	**0** Consistent with U.S. EPA (1994), U.S. EPA (1994b), and NC DEHNR (1997), U.S. EPA OSW recommends that the default value assumed for *kse* is zero because of contaminated soil eroding onto the site and away from the site. uncertainty may overestimate *kse*.
X_e	Unit soil loss	kg/m^2-yr	**Varies** This variable is site-specific and is calculated by using the equation in Table B-4-13. The following uncertainty is associated with this variable: All of the equation variables are site-specific. Use of default values rather than site-specific values for any or all of these variables will result in unit soil loss (X_e) estimates that are under- or overestimated to some degree. Based on default values, X_e estimates can vary over a range of less than two orders of magnitude.

TABLE B-2-3

COPC LOSS CONSTANT DUE TO SOIL EROSION (CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Variable	Description	Units	Value
SD	Sediment delivery ratio	unitless	**Varies** This value is site-specific and is calculated by using the equation in Table B-4-14. Uncertainties associated with this variable include the following: (1) The recommended default values for the empirical intercept coefficient, *a*, are average values that are based on studies of sediment yields from various watersheds. Therefore, those default values may not accurately represent site-specific watershed conditions. As a result, use of these default values may under- or overestimate *SD*. (2) The recommended default value for the empirical slope coefficient, *b*, is based on a review of sediment yields from various watersheds. This single default value may not accurately represent site-specific watershed conditions. As a result, use of this default value may under- or overestimate *SD*.
ER	Soil enrichment ratio	unitless	**Inorganics: 1** **Organics: 3** COPC enrichment occurs because (1) lighter soil particles erode more than heavier soil particles, and (2) concentration of organic COPCs—which is a function of organic carbon content of sorbing media—is expected to be higher in eroded material than in *in-situ* soil (U.S. EPA 1993). In the absence of site-specific data, U.S. EPA OSW recommends a default value of 3 for organic COPCs and 1 for inorganic COPCs. This is consistent with other U.S. EPA guidance (1993), which recommends a range of 1 to 5 and a value of 3 as a "reasonable first estimate." This range has been used for organic matter, phosphorus, and other soil-bound COPCs (U.S. EPA 1993); however, no sources or references were provided for this range. *ER* is generally higher in sandy soils than in silty or loamy soils (U.S. EPA 1993). The following uncertainty is associated with this variable: The default *ER* value may not accurately reflect site-specific conditions; therefore, *kse* may be over- or underestimated to an unknown extent. The extent of any uncertainties will be reduced by using county-specific ER values.
BD	Soil bulk density	g soil/cm^3 soil	**1.5** This variable is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil (Hillel 1980), as summarized in U.S. EPA (1990). A range of 0.83 to 1.84 was originally cited in Hoffman and Baes (1979). U.S. EPA (1994b) recommended a default *BD* value of 1.5 g/cm^3, based on a mean value for loam soil that was taken from Carsel, Parrish, Jones, Hansen, and Lamb (1988). The value of 1.5 g/cm^3 also represents the midpoint of the "relatively narrow range" for *BD* of 1.2 to 1.7 g/cm^3 (U.S. EPA 1993). The following uncertainty is associated with this variable: The recommended soil bulk density value may not accurately represent site-specific soil conditions.

TABLE B-2-3

COPC LOSS CONSTANT DUE TO SOIL EROSION (CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Variable	Description	Units	Value
Z_s	Soil mixing zone depth	cm	**1 to 20** U.S. EPA recommends the following values for this variable: <u>Soil</u> / <u>Depth (cm)</u> / <u>Reference</u> Untilled / 1 / U.S. EPA (1990a) and U.S. EPA (1993a) Tilled / 20 / U.S. EPA (1990a) and U.S. EPA (1993a) U.S. EPA (1990) does not provide a reference for these values. U.S. EPA (1993) cites U.S. EPA (1994a). Uncertainties associated with this variable include the following: (1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *kse*. (2) Deposition to hard surfaces may result in dust residues that have negligible dilution in comparison to that of other residues. This uncertainty may underestimate *kse*.
Kd_s	Soil-water partition coefficient	mL water/g soil (or cm^3 water/g soil)	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Uncertainties associated with this parameter will be limited if Kd_s values are calculated as described in Appendix A-3.
θ_{sw}	Soil volumetric water content	mL water/cm^3 soil	**0.2** This variable is site-specific, and depends on the available water and on soil structure; θ_{sw} can be estimated as the midpoint between a soil's field capacity and wilting point, if a representative watershed soil can be identified. However, U.S. EPA OSW recommends the use of 0.2 mL/cm^3 as a default value. This value is the midpoint of the range 0.1 (very sandy soils) to 0.3 (heavy loam/clay soils) recommended by U.S. EPA (1993) (no source or reference is provided for this range) and is consistent with U.S. EPA (1994b). The following uncertainty is associated with this variable: The default θ_{sw} value may not accurately reflect site-specific or local conditions; therefore, *kse* may be under- or overestimated to a small extent, based on the limited range of values.

TABLE B-2-3

COPC LOSS CONSTANT DUE TO SOIL EROSION (CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

REFERENCES AND DISCUSSION

Carsel, R.F., R.S. Parish, R.L. Jones, J.L. Hansen, and R.L. Lamb. 1988. "Characterizing the Uncertainty of Pesticide Leaching in Agricultural Soils." *Journal of Contaminant Hydrology*. Vol. 2. Pages 11-24.

This document is cited by U.S. EPA (1994b) as the source for a mean soil bulk density, *BD*, value of 1.5 (g soil/cm^3 soil) for loam soil.

Hillel, D. 1980. *Fundamentals of Soil Physics*. Academic Press, Inc. New York.

This document is cited by U.S. EPA (1990) for the statement that soil bulk density, *BD*, is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil.

Hoffman, F.O., and C.F. Baes. 1979. *A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides.* ORNL/NUREG/TM-882.

This document presents a soil bulk density, *BD*, range of 0.83 to 1.84.

U.S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600-90-003. January.

This document presents a range of values for soil mixing zone depth, Z_s, for tilled and untilled soil. The basis or source of these values is not identified.

U.S. EPA. 1993. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, D.C. November 1993.

This document is the source of a range of COPC enrichment ratio, *ER*, values. The recommended range, 1 to 5, has been used for organic matter, phosphorous, and other soul-bound COPCs. This document recommends a value of 3 as a "reasonable first estimate," and states that COPC enrichment occurs because lighter soil particles erode more than heavier soil particles. Lighter soil particles have higher ratios of surface area to volume and are higher in organic matter content. Therefore, concentration of organic COPCs, which is a function of the organic carbon content of sorbing media, is expected to be higher in eroded material than in *in situ* soil.

This document is also a source of the following:

- A "relatively narrow range" for soil bulk density, *BD*, of 1.2 to 1.7 (g soil/cm^3 soil)
- COPC-specific (inorganic COPCs only) Kd_s values used to develop a proposed range (2 to 280,000 [mL water/g soil]) of Kd_s values
- A range of soil volumetric water content (θ_{sw}) values of 0.1 (mL water/cm^3 soil) (very sandy soils) to 0.3 (mL water/cm^3 soil) (heavy loam/clay soils) (however, no source or reference is provided for this range)
- A range of values for soil mixing zone depth, Z_s, for tilled and untilled soil

U.S. EPA. 1994. *Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* April 15.

U.S. EPA. 1994a. *Estimating Exposure to Dioxin-Like Compounds. Volume III: Site-specific Assessment Procedures.* External Review Draft. Office of Research and Development. Washington, D.C. EPA/600/6-88/005Cc. June.

This document is the source of values for soil mixing zone depth, Z_s, for tilled and untilled soil, as cited in U.S. EPA (1993).

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document recommends (1) a default soil bulk density value of 1.5 (g soil/cm^3 soil), based on a mean value for loam soil that is taken from Carsel, Parrish, Jones, Hansen, and Lamb (1988), and (2) a default soil volumetric water content, θ_{sw}, value of 0.2 (mL water/cm^3 soil), based on U.S. EPA (1993).

TABLE B-2-4

COPC LOSS CONSTANT DUE TO RUNOFF (CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Description

This equation calculates the COPC loss constant due to runoff of soil. Uncertainties associated with this equation include the following:

(1) For soluble COPCs, leaching might result in movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksr*.
(2) Deposition to hard surfaces may result in dust residues that have negligible dilution in comparison to that of other residues. This uncertainty may underestimate *ksr*.

Equation

$$ksr = \frac{RO}{\theta_{sw} \cdot Z_s} \cdot \left(\frac{1}{1 + (Kd_s \cdot BD / \theta_{sw})} \right)$$

Variable	Description	Units	Value
ksr	COPC loss constant due to runoff	yr^{-1}	
RO	Average annual surface runoff from pervious areas	cm/yr	**Varies** This variable is site-specific. According to U.S. EPA (1993), U.S. EPA (1994b), and NC DEHNR (1997), average annual surface runoff, *RO*, can be estimated by using the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973). According to NC DEHNR (1997), estimates can also be made by using more detailed, site-specific procedures for estimating the amount of surface runoff, such as those based on the U.S. Soil Conservation Service curve number equation (CNE). U.S. EPA (1985) is cited as an example of such a procedure. The following uncertainty is associated with this variable: To the extent that site-specific or local average annual surface runoff information is not available, default or estimated values may not accurately represent site-specific or local conditions. As a result, *ksl* may be under- or overestimated to an unknown degree.

Variable	Description	Units	Value
θ_{sw}	Soil volumetric water content	mL water/cm^3 soil	**0.2** This variable depends on the available water and soil structure; if a representative watershed soil can be identified, θ_{sw} can be estimated as the midpoint between a soil's field capacity and wilting point. U.S. EPA OSW recommends the use of 0.2 mL/cm^3 as a default value. This value is the midpoint of the range 0.1 (very sandy soils) to 0.3 (heavy loam/clay soils), which is recommended by U.S. EPA (1993) (no source or reference is provided for this range), and is consistent with U.S. EPA (1994b) and NC DEHNR (1997). The following uncertainty is associated with this variable: The default θ_{sw} value may not accurately reflect site-specific or local conditions; therefore, *kse* may be under- or overestimated to a small extent, based on the limited range of values.
Z_s	Soil mixing zone depth	cm	**1 to 20** U.S. EPA OSW recommends the following values for this variable: Soil / Depth (cm) / Reference Untilled / 1 / U.S. EPA (1990a) and U.S. EPA (1993a) Tilled / 20 / U.S. EPA (1990a) and U.S. EPA (1993a) U.S. EPA (1990) does not provide a reference for these values. U.S. EPA (1993a) cites U.S. EPA (1994a). Uncertainties associated with this variable include the following: (1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksr*. (2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in-situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksr*.
Kd_s	Soil-water partition coefficient	mL water/g soil (or cm^3 water/g soil)	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Uncertainties associated with this parameter will be limited if Kd_s values are calculated as described in Appendix A-3.

TABLE B-2-4

COPC LOSS CONSTANT DUE TO RUNOFF
(CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

(Page 3 of 5)

Variable	Description	Units	Value
BD	Soil bulk density	g soil/cm^3 soil	**1.5** This variable is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil (Hillel 1980), as summarized in U.S. EPA (1990). The proposed range was originally cited in Hoffman and Baes (1979). U.S. EPA (1994b) recommended a default soil bulk density value of (1.5 g soil/cm^3 soil), based on a mean value for loam soil that is taken from Carsel, Parrish, Jones, Hansen, and Lamb (1988). The value of 1.5 (g soil/cm^3 soil) also represents the midpoint of the "relatively narrow range" for *BD* of 1.2 to 1.7 (g soil/cm^3 soil) (U.S. EPA 1993). The following uncertainty is associated with this variable: The recommended soil bulk density value may not accurately represent site-specific soil conditions.

REFERENCES AND DISCUSSION

Carsel, R.F., R.S. Parrish, R.L. Jones, J.L. Hansen, and R.L. Lamb. 1988. "Characterizing the Uncertainty of Pesticide Leaching in Agricultural Soils." *Journal of Contaminant Hydrology*. Vol. 2. Pages 11-24.

This document is cited by U.S. EPA (1994b) as the source of a mean soil bulk density, *BD*, value of 1.5 (g soil/cm^3 soil) for loam soil.

Geraghty, J.J., D.W. Miller, F. Van der Leeden, and F.L. Troise. 1973. *Water Atlas of the United States*. Water Information Center, Port Washington, New York.

This document is cited by U.S. EPA (1993), U.S. EPA (1994), and NC DEHNR (1997) as a reference to calculate average annual runoff, *RO*. This reference provides maps with isolines of annual average surface water runoff, which is defined as all flow contributions to surface water bodies, including direct runoff, shallow interflow, and ground water recharge. Because these values are total contributions and not only surface runoff, U.S. EPA (1994) recommends that the volumes be reduced by 50 percent in order to estimate surface runoff.

Hillel, D. 1980. Fundamentals of Soil Physics. Academic Press, Inc. New York.

This document is cited by U.S. EPA (1990) for the statement that soil bulk density, *BD*, is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil.

Hoffman, F.O., and C.F. Baes. 1979. *A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides.* ORNL/NUREG/TM-882.

This document presents a soil bulk density, *BD*, range of 0.83 to 1.84.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is one of the source documents that cites the use of Table B-2-4; however, this document is not the original source of this equation (this source is unknown). This document also recommends the following:

- Estimation of annual current runoff, *RO* (cm/yr), by using the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973) or site-specific procedures, such as using the U.S. Soil Conservation Service curve number equation (CNE); U.S. EPA (1985) is cited as an example of such a procedure.
- Default value of 0.2 (mL water/cm^3 soil) for soil volumetric water content (θ_{sw})

U.S. EPA. 1985. *Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water—Part I (Revised. 1985).* Environmental Research Laboratory. Athens, Georgia. EPA/600/6-85/002a. September.

This document is cited by NC DEHNR (1997) as an example of the use of the U.S. Soil Conservation Service CNE to estimate site-specific surface runoff.

U.S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600-90-003. January.

This document presents a range of values for soil mixing zone depth, Z_s, for tilled and untilled soil; the basis for, or sources of, these values is not identified.

COPC LOSS CONSTANT DUE TO RUNOFF (CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

U.S. EPA. 1994a. *Estimating Exposure to Dioxin-Like Compounds. Volume III: Site-specific Assessment Procedures.* External Review Draft. Office of Research and Development. Washington, D.C. EPA/600/6-88/005Cc June..

This document presents a range of values for soil mixing zone depth, Z_s, for tilled and untilled soil as cited in U.S. EPA (1993).

U.S. EPA. 1993. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, D.C. November.

This document recommends the following:

- A "relatively narrow range" for soil bulk density, *BD*, of 1.2 to 1.7 (g soil/cm^3 soil)
- A range of soil volumetric water content, θ_{sw}, values of 0.1 (very sandy soils) to 0.3 (heavy loam/clay soils) (the original source of, or reference for, these values is not identified)
- A range of values for soil mixing depth, Z_s, for tilled and untilled soil (the original source of, or reference for, these values is not identified)
- A range (2 to 280,000 [mL water/g soil) of Kd_s values for inorganic COPCs
- Use of the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973) to calculate average annual runoff, *RO*.

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes.* Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities. Offices of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document recommends the following:

- Estimation of average annual runoff, *RO*, by using the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973)
- Default soil bulk density, *BD*, value of 1.5 (g soil/cm^3 soil), based on the mean for loam soil that is taken from Carsel, Parrish, Jones, Hansen, and Lamb (1988)
- Default soil volumetric water content, θ_{sw}, value of 0.2 (mL water/cm^{3}soil), based on U.S. EPA (1993)

COPC LOSS CONSTANT DUE TO LEACHING
(CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Description

This equation calculates the constant for COPC loss resulting from leaching of soil. Uncertainties associated with this equation include the following:

(1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksl*.

(2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksl*.

(3) The original source of this equation has not been identified. U.S. EPA (1993) presents the equation as shown here. U.S. EPA (1994b) and NC DEHNR (1997) replaced the numerator as shown with "*q*", defined as average annual recharge (cm/yr).

Equation

$$ksl = \frac{P + I - RO - E_v}{\theta_{sw} \cdot Z_s \cdot \left[1.0 + \left(BD \cdot Kd_s / \theta_{sw}\right)\right]}$$

Variable	Description	Units	Value
ksl	COPC loss constant due to leaching	yr^{-1}	
P	Average annual precipitation	cm/yr	**18.06 to 164.19** This variable is site-specific. This range is based on information presented in U.S. EPA (1990), representing data for 69 selected cities (U.S. Bureau of Census 1987; Baes, Sharp, Sjoreen and Shor 1984). The 69 selected cities are not identified; however, they appear to be located throughout the continental United States. U.S. EPA OSW recommends that site-specific data be used. The following uncertainty is associated with this variable: (1) To the extent that a site is not located near an established meteorological data station, and site-specific data are not available, default average annual precipitation data may not accurately reflect site-specific conditions. As a result, *ksl* may be under- or overestimated. However, average annual precipitation data are reasonably available; therefore, uncertainty introduced by this variable is expected to be minimal.

TABLE B-2-5

COPC LOSS CONSTANT DUE TO LEACHING
(CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Variable	Description	Units	Value
I	Average annual irrigation	cm/yr	**0 to 100** This variable is site-specific. This range is based on information presented in U.S. EPA (1990), representing data for 69 selected cities (Baes, Sharp, Sjoreen, and Shor 1984). The 69 selected cities are not identified; however, they appear to be located throughout the continental United States. The following uncertainty is associated with this variable: To the extent that site-specific or local average annual irrigation information is not available, default values (generally based on the closest comparable location) may not accurately reflect site-specific conditions. As a result, *ksl* may be under- or overestimated to an unknown degree.
RO	Average annual surface runoff from pervious areas	cm/yr	**Varies** This variable is site-specific. According to U.S. EPA (1993), U.S. EPA (1994). and NC DEHNR (1997), average annual surface runoff, *RO*, can be estimated by using the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973). According to NC DEHNR (1997), this estimate can also be made by using more detailed, site-specific procedures, such as those based on the U.S. Soil Conservation Service CNE. The following uncertainty is associated with this variable: To the extent that site-specific or local average annual surface runoff information is not available, default or estimated values may not accurately represent site-specific or local conditions. As a result, *ksl* may be under- or overestimated to an unknown degree.
E_v	Average annual evapotranspiration	cm/yr	**35 to 100** This variable is site-specific. This range is based on information presented in U. S. EPA (1990), representing data from 69 selected cities. The 69 selected cities are not identified; however, they appear to be located throughout the continental United States. The following uncertainty is associated with this variable: To the extent that site-specific or local average annual evapotranspiration information is not available, default values may not accurately reflect site-specific conditions. As a result, *ksl* may be under- or overestimated to an unknown degree.

Variable	Description	Units	Value
θ_{sw}	Soil volumetric water content	(mL water/cm^3 soil)	**0.2** This variable is site-specific, and depends on the available water and on soil structure; if a representative watershed soil can be identified θ_{sw} can be estimated as the midpoint between a soil's field capacity and wilting point. U.S. EPA OSW recommends the use of 0.2 mL/cm^3 as a default value. This value is the midpoint of the range of 0.1 (very sandy soils) to 0.3 (heavy loam/clay soils) recommended by U.S. EPA (1993) (no source or reference is provided for this range) and is consistent with U.S. EPA (1994b) and NC DEHNR (1997). The following uncertainty is associated with this variable: The default θ_{sw} value may not accurately reflect site-specific or local conditions; therefore, *ksl* may be under- or overestimated to a small extent, based on the limited range of values.
Z_s	Soil mixing zone depth	cm	**1 to 20** U.S. EPA OSW recommends the following values for this variable: Soil — Depth (cm) — Reference Untilled — 1 — U.S. EPA (1990a) and U.S. EPA (1993a) Tilled — 20 — U.S. EPA (1990a) and U.S. EPA (1993a) U.S. EPA (1990) does not provide a reference for these values. U.S. EPA (1993a) cites U.S. EPA (1994a). Uncertainties associated with this variable include the following: (1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksr*. (2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in-situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksl*.
BD	Soil bulk density	g soil/cm^3 soil	**1.5** This variable is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil (Hillel 1980), as summarized in U.S. EPA (1990). A range of 0.83 to 1.84 was originally cited in Hoffman and Baes (1979). U.S. EPA (1994b) recommended a default soil bulk density value of 1.5 (g soil/cm^3 soil), based on a mean value for loam soil from Carsel, Parrish, Jones, Hansen, and Lamb (1988). The value of 1.5 (g soil/cm^3 soil) also represents the midpoint of the "relatively narrow range" for *BD* of 1.2 to 1.7 (g soil/cm^3 soil) (U.S. EPA 1993). The following uncertainty is associated with this variable: The recommended soil bulk density value may not accurately represent site-specific soil conditions.

COPC LOSS CONSTANT DUE TO LEACHING (CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Variable	Description	Units	Value
Kd_s	Soil-water partition coefficient	cm^3 water/g soil	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Uncertainties associated with this parameter will be limited if Kd_s values are calculated as described in Appendix A-3.

REFERENCES AND DISCUSSION

Baes, C.F., R.D. Sharp, A.L. Sjoreen and R.W. Shor. 1984. "A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture." Prepared for the U.S. Department of Energy under Contract No. DEAC05-840R21400.

For the continental United States, as cited in U.S. EPA (1990), this document is the source of a series of maps showing: (1) average annual precipitation (*P*), (2) average annual irrigation (*I*), and (3) average annual evapotranspiration isolines.

Carsel, R.F., R.S. Parrish, R.L. Jones, J.L. Hansen, and R.L. Lamb. 1988. "Characterizing the Uncertainty of Pesticide Leaching in Agricultural Soils." *Journal of Contaminant Hydrology.* Vol. 2. Pages 11-24.

This document is cited by U.S. EPA (1994b) as the source for a mean soil bulk density value, *BD*, of 1.5 g/cm^3 for loam soil.

Geraghty, J.J., D.W. Miller, F. Van der Leeden, and F.L. Troise. 1973. *Water Atlas of the United States.* Water Information Center, Port Washington, New York.

This document is cited by U.S. EPA (1993), U.S. EPA (1994b), and NC DEHNR (1997) as a reference for calculating average annual runoff, *RO*. This document provides maps with isolines of annual average surface runoff, which is defined as all flow contributions to surface water bodies, including direct runoff, shallow interflow, and ground water recharge. Because these volumes are total contributions and not only surface runoff, U.S. EPA (1994b) recommends that the volumes be reduced by 50 percent in order to estimate average annual surface runoff.

This document presents a soil bulk density, *BD*, range of 0.83 to 1.84.

Hillel, D. 1980. *Fundamentals of Soil Physics.* Academic Press, Inc. New York, New York.

This document is cited by U.S. EPA (1990) for the statement that soil bulk density, *BD*, is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil.

Hoffman, F.O., and C.F. Baes. 1979. *A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides.* ORNL/NUREG/TM-882.

This document presents a soil bulk density, *BD*, range of 0.83 to 1.84.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is one of the source documents that cites the use of the equation in Table B-1-5. However, the document is not the original source of this equation. This document also recommends the following:

- Estimation of average annual surface runoff, *RO* (cm/yr), by using the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973) or site-specific procedures, such as using the U.S. Soil Conservation Service CNE; U.S. EPA 1985 is cited as an example of such a procedure.
- A default value of 0.2 (mL water/cm^3 soil) for soil volumetric water content, θ_{sw}

U.S. Bureau of the Census. 1987. *Statistical Abstract of the United States:* 1987. 107th edition. Washington, D.C.

This document is a source of average annual precipitation (*P*) information for 69 selected cites, as cited in U.S. EPA (1990); these 69 cities are not identified.

U.S. EPA. 1985. *Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Groundwater.* Part I (Revised 1985). Environmental Research Laboratory. Athens, Georgia. EPA/600/6-85/002a. September.

This document is cited by NC DEHNR (1997) as an example of the use of the U.S. Soil Conservation Service CNE to estimate *RO*.

U.S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600-90-003. January.

This document presents ranges of (1) average annual precipitation, (2) average annual irrigation, and (3) average annual evapotranspiration. This document cites Baes, Sharp, Sjoreen, and Shor (1984) and U.S. Bureau of the Census (1987) as the original sources of this information.

U.S. EPA. 1993. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, D.C. November.

This document is one of the reference sources for the equation in Table B-1-5; this document also recommends the following:

- A range of soil volumetric water content, θ_{sw}, values of 0.1 (very sandy soils) to 0.3 (heavy loam/clay soils); the original source or reference for these values is not identified.
- A range of values for soil mixing depth, Z_s, for tilled and untilled soil; the original source reference for these values is not identified.
- A range (2 to 280,000 [mL water/g soil]) of Kd_s values for inorganic COPCs
- A "relatively narrow range" for soil bulk density, *BD*, of 1.2 to 1.7 (g soil/cm^3 soil)

This document is one of the reference source documents for the equation in Table B-1-5. The original source of this equation is not identified. This document also presents a range of values for soil mixing depth, *Z*, for tilled and untilled soil; the original source of these values is not identified. Finally, this document presents several COPC-specific Kd_s values that were used to establish a range (2 to 280,000 [mL water/g soil]) of Kd_s values.

U.S. EPA. 1994a. *Estimating Exposure to Dioxin-Like Compounds. Volume III: Site-specific Assessment Procedures.* External Review Draft Office of Research and Development. Washington, D.C. EPA/600/6-88/005Cc June..

This document presents values for soil mixing depth, Z_s, for tilled and untilled soil, as cited in U.S. EPA (1993).

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document recommends (1) a default soil volumetric water content, θ_{sw}, value of 0.2 (mL water/cm^3 soil), based on U.S. EPA (1993), and (2) a default soil bulk density, *BD*, value of 1.5 (g soil/cm^3 soil), based on a mean value for loam soil from Carsel, Parrish, Jones, Hansen, and Lamb (1988).

TABLE B-2-6

COPC LOSS CONSTANT DUE TO VOLATILIZATION
(CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Description

This equation calculates the COPC loss constant from soil due to volatilization. Consistent with U.S. EPA guidance (1994) and based on the need for additional research to be conducted to determine the magnitude of the uncertainty introduced for modeling volatile COPCs from soil, U.S. EPA OSW recommends that, until identification and validation of more applicable models, the constant for the loss of soil resulting from volatilization (*ksv*) should be set equal to zero. In cases where high concentrations of volatile organic compounds are expected to be present in the soil and the permitting authority considers calculation of *ksv* to be appropriate, the equation presented in this table should be considered. U.S. EPA OSW also recommends consulting the methodologies described in U.S. EPA NCEA document, *Methodology for Assessing Health Risks Associated with Multiple Exposure Pathways to Combustor Emissions* (In Press). Uncertainties associated with this equation include the following:

(1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksv*.

(2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksv*.

Equation

$$ksv = \left[\frac{3.1536 \cdot 10^{7} \cdot H}{Z_s \cdot Kd_s \cdot R \cdot T_a \cdot BD}\right] \cdot \left[0.482 \cdot W^{0.78} \cdot \left(\frac{\mu_a}{\rho_a \cdot D_a}\right)^{-0.67} \cdot \left(\sqrt{\frac{4A}{\pi}}\right)^{-0.11}\right]$$

Variable	Definition	Units	Value
ksv	COPC loss constant due to volatilization	yr^{-1}	**0** Consistent with U.S. EPA guidance (1994) and based on the need for additional research to be conducted to determine the magnitude of the uncertainty introduced for modeling volatile COPCs from soil, U.S. EPA OSW recommends that, until identification and validation of more applicable models, the constant for the loss of soil resulting from volatilization (*ksv*) should be set equal to zero.
0.482	Empirical constant	unitless	This is an empirical constant calculated during the development of this equation.
0.78	Empirical constant	unitless	This is an empirical constant calculated during the development of this equation.
-0.67	Empirical constant	unitless	This is an empirical constant calculated during the development of this equation.
-0.11	Empirical constant	unitless	This is an empirical constant calculated during the development of this equation.
$3.1536 \times 10^{+07}$	Units conversion factor	s/yr	

TABLE B-2-6

COPC LOSS CONSTANT DUE TO VOLATILIZATION
(CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Variable	Definition	Units	Value
H	Henry's Law constant	atm-m^3/mol	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Values for this variable, estimated by using the parameters and algorithms in Appendix A-3, may under- or overestimate the actual COPC-specific values. As a result, *ksv* may be under- or overestimated.
Z_s	Soil mixing zone depth	cm	**1 to 20** U.S. EPA OSW recommends the following values for this variable: <u>Soil</u> — <u>Depth (cm)</u> — <u>Reference</u> Untilled — 1 — U.S. EPA (1990a) and U.S. EPA (1993a) Tilled — 20 — U.S. EPA (1990a) and U.S. EPA (1993a) U.S. EPA (1990) does not provide a reference for these values. U.S. EPA (1993a) cites U.S. EPA (1994a). Uncertainties associated with this variable include the following: (1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksr*. (2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksv*.
Kd_s	Soil-water partition coefficient	cm^3 water/g soil	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Uncertainties associated with this parameter will be limited if Kd_s values are calculated as described in Appendix A-3.
R	Universal gas constant	atm-m^3/mol-K	**8.205×10^{-5}** There are no uncertainties associated with this parameter.

TABLE B-2-6

COPC LOSS CONSTANT DUE TO VOLATILIZATION (CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Variable	Definition	Units	Value
T_a	Ambient air temperature	K	**298** This variable is site-specific. U.S. EPA (1990) also recommends an ambient air temperature of 298 K. The following uncertainty is associated with this variable: To the extent that site-specific or local values for the variable are not available, default values may not accurately represent site-specific conditions. The uncertainty associated with the selection of a single value from within the temperature range at a single location is expected to be more significant than the uncertainty associated with choosing a single ambient temperature to represent all localities.
BD	Soil bulk density	g soil/cm^3 soil	**1.5** This variable is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil (Hillel 1980), as summarized in U.S. EPA (1990). A range of 0.83 to 1.84 was originally cited in Hoffman and Baes (1979). U.S. EPA (1994b) recommended a default soil bulk density value of 1.5 g/cm^3, based on a mean value for loam soil from Carsel, Parrish, Jones, Hansen, and Lamb (1988). The value of 1.5 g/cm^3 also represents the midpoint of the "relatively narrow range" for *BD* of 1.2 to 1.7 g/cm^3 (U.S. EPA 1993). The following uncertainty is associated with this variable: The recommended soil bulk density value may not accurately represent site-specific soil conditions.
W	Average annual wind speed	m/s	**3.9** Consistent with U.S. EPA (1990), U.S. EPA OSW recommends a default value of 3.9 m/s. See Chapter 3 for guidance regarding the references and methods used to determine a site-specific value that isconsistent with air dispersion modeling. The following uncertainty is associated with this variable: To the extent that site-specific or local values for this variable are not available, default values may not accurately represent site-specific conditions. The uncertainty associated with the selection of a single value from within the range of windspeeds at a single location may be more significant than the uncertainty associated with choosing a single windspeed to represent all locations.

TABLE B-2-6

COPC LOSS CONSTANT DUE TO VOLATILIZATION (CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Variable	Definition	Units	Value
μ_a	Viscosity of air	g/cm-s	**1.81×10^{-04}** U.S. EPA OSW recommends the use of this value, based on Weast (1980). This value applies at standard conditions (20°C or 298 K and 1 atm or 760 mm Hg). The viscosity of air may vary slightly with temperature.
ρ_a	Density of air	g/cm^3	**0.0012** U.S. EPA OSW recommends the use of this value, based on Weast (1980. This value applies at standard conditions (20°C or 298 K and 1 atm or 760 mm Hg). The density of air will vary slightly with temperature.
D_a	Diffusivity of COPC in air	cm^2/s	**Varies** This value is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: The default D_a values may not accurately represent the behavior of COPCs under site-specific conditions. However, the degree of uncertainty is expected to be minimal.
A	Surface area of contaminated area	m^2	**1.0** See Chapter 5 for guidance regarding the calculation of this value.

REFERENCES AND DISCUSSION

Carsel, R.F., R.S, Parrish, R.L. Jones, J.L. Hansen, and R.L. Lamb. 1988. "Characterizing the Uncertainty of Pesticide Leaching in Agricultural Soils." *Journal of Contaminant Hydrology.* Vol. 2. Pages 11-24.

This document is cited by U.S. EPA (1994b) as the source of a mean soil bulk density value, *BD*, of 1.5 (g soil/cm^3 soil) for loam soil.

Hillel, D. 1980. *Fundamentals of Soil Physics.* Academic Press, Inc. New York, New York.

Hoffman, F.O., and C.F. Baes. 1979. *A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides.* ORNL/NUREG/TM-882.

This document presents a soil bulk density, *BD*, range of 0.83 to 1.84.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is one of the source documents that cites the use of the equation in Table B-1-6; however, the original source of this equation is not identified.

U. S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600-90-003. January.

This document recommends the following:

- A range of values for soil mixing zone depth, Z_s, for tilled and untilled soil; however, the source or basis for these values is not identified
- A default ambient air temperature of 298 K
- An average annual wind speed of 3.9 m/s; however, no source or reference for this value is identified.

U.S. EPA. 1993. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, D.C. November.

This document is one of the reference source documents for the equation in Table B-1-6; however, the original reference for this equation is not identified.

This document also presents the following:

- A range of values for soil mixing depth, Z_s, for tilled and untilled soil; however, the original source of these values is not identified.
- COPC-specific Kd_s values that were used to establish a range (2 to 280,000 [mL water/g soil]) of Kd_s values for inorganic COPCs
- A "relatively narrow range" for soil bulk density, *BD*, of 1.2 to 1.7 (g soil/cm^3 soil)

U.S. EPA. 1994. *Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* April 15.

U.S. EPA. 1994a. *Estimating Exposure to Dioxin-Like Compounds. Volume III: Site-specific Assessment Procedures.* External Review Draft. Office of Research and Development. Washington, D.C. EPA/600/6-88/005Cc. June.

This document presents value for soil, mixing depth, Z_s, for tilled and untilled soil as cited in U.S. EPA (1993).

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Waste. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document recommends a default soil density, *BD*, value of 1.5 (g soil/cm^3 soil), based on a mean value for loam soil that is taken from Carsel, Parrish, Jones, Hansen, and Lamb (1988).

Weast, R.C. 1980. *Handbook of Chemistry and Physics.* 61st Edition. CRC Press, Inc. Cleveland, Ohio.

This document is cited by NC DEHNR (1997) as the source recommended values for viscosity of air, μ_a, and density of air, ρ_a.

TABLE B-2-7

ABOVEGROUND PRODUCE CONCENTRATION DUE TO DIRECT DEPOSITION (CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Description

This equation calculates the COPC concentration in aboveground vegetation, due to wet and dry deposition of COPCs onto plant surfaces. The limitations and uncertainty in calculating this value include the following:

(1) Uncertainties associated with the variables *Q*, *Dydp*, and *Dywp* are site-specific.

(2) The calculation of *kp* values does not consider chemical degradation processes. Inclusion of chemical degradation process would decrease the amount of time that a chemical remains on plant surfaces (half-time) and thereby increase *kp* values. *Pd* decreases with increased *kp* values. Reduction of half-time from the assumed 14 days to 2.8 days, for example, would decrease *Pd* about 5-fold.

(3) The calculation of other parameter values (for example, *Fw* and *Rp*) is based directly or indirectly on studies of vegetation other than aboveground produce (primarily grasses). To the extent that the calculated parameter values do not accurately represent aboveground produce-specific values, uncertainty is introduced.

(4) The uncertainties associated with the variables F_v, *Tp*, and *Yp* are not expected to be significant.

As highlighted above, *Pd* is most significantly affected by the values assumed for *kp* and the extent to which parameter values (assumed based on studies of pasture grass) accurately reflect aboveground produce-specific values.

Equation

$$Pd = \frac{1000 \cdot Q \cdot (1 - F_v) \cdot [Dydp + (Fw \cdot Dywp)] \cdot Rp \cdot [1.0 - \exp(-kp \cdot Tp)]}{Yp \cdot kp}$$

For mercury modeling

$$Pd = \frac{1000 \cdot 0.48Q \cdot (1 - F_v) \cdot [Dydp + (Fw \cdot Dywp)] \cdot Rp \cdot [1.0 - \exp(-kp \cdot Tp)]}{Yp \cdot kp}$$

Use *0.48Q* for total mercury and $F_v = 0.85$ in the mercury modeling equation to calculate *Pd*. The calculated *Pd* value is apportioned into the divalent mercury (Hg^{2+}) and methyl mercury (MHg) forms based on the 78% Hg^{2+} and 22% MHg speciation split in aboveground produce (see Chapter 2).

$$Pd(Hg^{2+}) = 0.78\,Pd$$
$$Pd(Mhg) = 0.22\,Pd$$

Evaluate divalent and methyl mercury as individual COPCs. Calculate *Pd* for divalent and methyl mercury using the corresponding values.

ABOVEGROUND PRODUCE CONCENTRATION DUE TO DIRECT DEPOSITION (CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Variable	Description	Units	Value
Pd	Concentration of COPC in aboveground produce due to direct (wet and dry) deposition	mg COPC/kg DW	
1000	Units conversion factor	mg/g	
Q	COPC-specific emission rate	g/s	**Varies** This value is COPC- and site-specific and is determined by air dispersion modeling. See Chapters 2 and 3 for guidance regarding the calculation of this variable. Uncertainties associated with this variable are also COPC- and site-specific.
F_v	Fraction of COPC air concentration in vapor phase	unitless	**0 to 1** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values is presented in Appendix A-3. This range is based on values presented in Appendix A-3. Values are also presented in U.S. EPA (1994b) and NC DEHNR (1997). F_v was calculated using an equation presented in Junge (1977) for all organic COPCs, including PCDDs and PCDFs. U.S. EPA (1994c) states that $F_v = 0$ for all metals (except mercury). The following uncertainties are associated with this variable: (1) It is based on the assumption of a default S_T value for background plus local sources, rather than an S_T value for urban sources. If a specific site is located in an urban area, the use of the latter S_T value may be more appropriate. Specifically, the S_T value for urban sources is about one order of magnitude greater than that for background plus local sources, and it would result in a lower calculated F_v value; however, the F_v value is likely to be only a few percent lower. (2) According to Bidleman (1988), the equation used to calculate F_v assumes that the variable *c* (Junge constant) is constant for all chemicals; however, the value of *c* depends on the chemical (sorbate) molecular weight, the surface concentration for monolayer coverage, and the difference between the heat of desorption from the particle surface and the heat of vaporization of the liquid phase sorbate. To the extent that site- or COPC-specific conditions may cause the value of *c* to vary, uncertainty is introduced if a constant value of *c* is used to calculate F_v. (3) Based on U.S. EPA (1994a), the F_v value for dioxins (PCDD/PCDF) is intended to represent 2, 3, 7, 8-TCDD TEQs by weighting data for all dioxin and furan congeners with nonzero TEFs. Uncertainty is introduced, because U.S. EPA has been unable to verify the recommended F_v value for dioxins.
Dydp	Unitized yearly average dry deposition from particle phase	s/m^2-yr	**Varies** This variable is COPC- and site-specific, and is determined by air dispersion modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.

Variable	Description	Units	Value
Rp	Interception fraction of the edible portion of plant	unitless	**0.39** U.S. EPA OSW recommends the use of this default *Rp* value because it represents the most current information available; specifically, productivity and relative ingestion rates. As summarized in Baes, Sharp, Sjoreen, and Shor (1984), experimental studies of pasture grasses identified a correlation between initial *Rp* values and productivity (standing crop biomass [*Yp*]) (Chamberlain 1970): $$Rp = 1 - e^{-\gamma \cdot Yp}$$ where *Rp* = Interception fraction of the edible portion of plant (unitless) γ = Empirical constant. Chamberlain (1970) presents a range of 2.3 to 3.3; Baes, Sharp, Sjoreen, and Shor (1984) uses 2.88, the midpoint for pasture grasses. *Yp* = Yield or standing crop biomass (productivity) (kg WW/m^2); the use of *Yp* value on a wet weight basis is in contrast to the equation presented in this table, which presents *Yp* on a dry weight basis. Baes, Sharp, Sjoreen, and Shor (1984) proposed using the same empirical relationship developed by Chamberlain (1970) for other vegetation classes. Class-specific estimates of the empirical constant, γ, were developed by forcing an exponential regression equation through several points, including average and theoretical maximum estimates of *Rp* and *Yp* (Baes, Sharp, Sjoreen, and Shor 1984). The class-specific *Rp* estimates were then weighted, by relative ingestion of each class, to arrive at the weighted average *Rp* value of 0.39. U.S. EPA (1994b) and U.S. EPA (1995) recommended a weighted average *Rp* value of 0.05. However, the relative ingestion rates used in U.S. EPA (1994b) and U.S. EPA (1995) to weight the average *Rp* value were derived from U.S. EPA (1992) and U.S. EPA (1994b). The most current guidance available for ingestion rates of homegrown produce is the 1997 *Exposure Factors Handbook* (U.S. EPA 1997). The default *Rp* value of 0.39 was weighted by relative ingestion rates of homegrown exposed fruit and exposed vegetables found in U.S. EPA (1997). Uncertainties associated with this variable include the following: (1) The empirical relationship developed by Chamberlain (1970) on the basis of a study of pasture grass may not accurately represent aboveground produce. (2) The empirical constants developed by Baes, Sharp, Sjoreen, and Shor (1984) for use in the empirical relationship developed by Chamberlain (1970) may not accurately represent site-specific mixes of aboveground produce.

TABLE B-2-7

ABOVEGROUND PRODUCE CONCENTRATION DUE TO DIRECT DEPOSITION (CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Variable	Description	Units	Value
Fw	Fraction of COPC wet deposition that adheres to plant surfaces	unitless	**0.2 for anions** **0.6 for cations and most organics** U.S. EPA OSW recommends using the chemical class-specific values of 0.2 for anions and 0.6 for cations and most organics and estimated by U.S. EPA (1994b) and U.S. EPA (1995). These values are the best available information, based on a review of the current scientific literature, with the following exception: U.S. EPA OSW recommends using an *Fw* value of 0.2 for the three organic COPCs that ionize to anionic forms. These include (1) 4-chloroaniline, (2) n-nitrosodiphenylamine, and (3) n-nitrosodi-n-proplyamine (see Appendix A-3). The values estimated by U.S. EPA (1994b) and U.S. EPA (1995) are based on information presented in Hoffman, Thiessen, Frank, and Blaylock (1992), which presented values for a parameter (*r*) termed the "interception fraction." These values were based on a study in which soluble radionuclides and insoluble particles labeled with radionuclides were deposited onto pasture grass via simulated rain. The parameter (*r*) is defined as "the fraction of material in rain intercepted by vegetation and initially retained" or, essentially, the product of *Rp* and *Fw*, as defined: $r = Rp \cdot Fw$ The *r* values developed by Hoffman, Thiessen, Frank, and Blaylock (1992) were divided by an *Rp* value of 0.5 for forage (U.S. EPA 1994b). The *Fw* values developed by U.S. EPA (1994b) are 0.2 for anions and 0.6 for cations and insoluble particles. U.S. EPA (1994b) and U.S. EPA (1995) recommends using the *Fw* value calculated by using the *r* value for insoluble particles to represent organic compounds; however, no rationale for this recommendation is provided. Interception values (*r*)—as defined by Hoffman, Thiessen, Frank, and Blaylock (1992)—have not been experimentally determined for aboveground produce. Therefore, U.S. EPA (1994b) and U.S. EPA (1995) apparently defaulted and assumed that the *Fw* values calculated for pasture grass (similar to forage) also apply to aboveground produce. The rationale for this recommendation is not provided. Uncertainties associated with this variable include the following: (1) Values of *r* developed experimentally for pasture grass may not accurately represent aboveground produce-specific *r* values. (2) Values of *r* assumed for most organic compounds, based on the behavior of insoluble polystryene microspheres tagged with radionuclides, may not accurately represent the behavior of organic compounds under site-specific conditions.
Dywp	Unitized yearly wet deposition in particle phase	s/m^2-yr	**Varies** This variable is COPC- and site-specific, and is determined by air dispersion modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.

TABLE B-2-7

ABOVEGROUND PRODUCE CONCENTRATION DUE TO DIRECT DEPOSITION (CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Variable	Description	Units	Value
kp	Plant surface loss coefficient	yr^{-1}	**18** U.S. EPA OSW recommends the *kp* value of 18 recommended by U.S. EPA (1993) and U.S. EPA (1994b). The *kp* value selected is the midpoint of a possible range of values (7.44 to 90.36). U.S. EPA (1990) identified several processes—including wind removal, water removal, and growth dilution—that reduce the amount of COPC that has been deposited on a plant surface. The term *kp* is a measure of the amount of contaminant lost to these physical processes over time. U.S. EPA (1990) cites Miller and Hoffman (1983) for the following equation used to estimate *kp*: $kp = (ln\,2 / t_{1/2}) \cdot 365$ days/yr where $t_{1/2}$ = half-time (days) Miller and Hoffman (1983) report half-time values ranging from 2.8 to 34 days for a variety of COPCs on herbaceous vegetation. These half-time values result in *kp* values of 7.44 to 90.36 (yr^{-1}). U.S. EPA (1993) and U.S. EPA (1994b) recommend a *kp* value of 18, based on a generic 14-day half-time, corresponding to physical processes only. The 14-day half-time is approximately the midpoint of the range (2.8 to 34 days) estimated by Miller and Hoffman (1983). Uncertainties associated with this variable include the following: (1) Calculation of *kp* does not consider chemical degradation processes. The addition of chemical degradation processes would decrease half-times and thereby increase *kp* values; plant concentration decreases as *kp* increases. Therefore, use of a *kp* value that does not consider chemical degradation processes is conservative. (2) The half-time values reported by Miller and Hoffman (1983) may not accurately represent the behavior of compounds on aboveground produce. (3) Based on this range (7.44 to 90.36), plant concentrations could range from about 1.8 times higher to about 5 times lower than the plant concentrations, based on a *kp* value of 18.

Variable	Description	Units	Value
Tp	Length of plant exposure to deposition per harvest of edible portion of plant	yr	**0.164** U.S. EPA OSW recommends using a *Tp* value of 0.164 years; this is consistent with U.S. EPA (1990), U.S. EPA (1993), U.S. EPA (1994b), and NC DEHNR (1997), which recommended treating *Tp* as a constant, based on the average period between successive hay harvests. Belcher and Travis (1989) estimated this period at 60 days. *Tp* is calculated as follows: 60 days ÷ 365 days/year = 0.164 years The following uncertainty is associated with this variable: The average period between successive hay harvests (60 days) may not reflect the length of the growing season or the length between successive harvests for site-specific aboveground produce crops. *Pd* will be (1) underestimated if the site-specific value of *Tp* is less than 60 days, or (2) overestimated if the site-specific value of *Tp* is more than 60 days.

Variable	Description	Units	Value
Yp	Yield or standing crop biomass of the edible portion of the plant (productivity)	kg DW/m^2	**Aboveground Produce: 2.24** U.S. EPA OSW recommends using the *Yp* value of 2.24. Based on a review of the available literature, this value appears to be representative of the most complete and thorough information. U.S. EPA (1990) states that the best estimate of *Yp* is productivity. Baes, Sharp, Sjoreen, and Shor (1984) and Shor, Baes, and Sharp (1982) define *Yp* as follows as: $Yp = Yh_i / Ah_i$ where Yh_i = Harvest yield of *i*th crop (kg DW) Ah_i = Area planted to *i*th crop (m^2) U.S. EPA (1994a) and NC DEHNR (1997) recommended using this equation. Class-specific *Yp* values were estimated by using average U.S. values for *Yh* and *Ah* for a variety of fruits and vegetables for 1993 (USDA 1994a and USDA 1994b). *Yh* values were converted to dry weight by using average conversion factors for fruits, fruiting vegetables, legumes, and leafy vegetables (Baes, Sharp, Sjoreen, and Shor 1984). Class-specific *Yp* values were grouped to reflect exposed fruits or exposed vegetables. Exposed fruit and exposed vegetable *Yp* values were then weighted by relative ingestion rates derived from the homegrown produce tables in U.S. EPA (1997). The average ingestion-weighted *Yp* value was 2.24. U.S. EPA (1994b) and U.S. EPA (1995) recommend a *Yp* value of 1.6; however, the produce classes and relative ingestion rates used to derive this *Yp* value are inconsistent with U.S. EPA (1997). The following uncertainty is associated with this variable: The harvest yield (*Yh*) and area planted (*Ah*) may not reflect site-specific conditions. This may under- or overestimate *Yp*.

REFERENCES AND DISCUSSION

Baes, C.F., R.D. Sharp, A.L. Sjoreen, and R.W. Shor. 1984. *Review and Analysis of Parameters and Assessing Transport of Environmentally Released Radionuclides through Agriculture.* ORNL-5786. Oak Ridge National Laboratory. Oak Ridge, Tennessee. September.

This document proposed using the same empirical relationship developed by Chamberlain (1970) for other vegetation classes. Class-specific estimates of the empirical constant, γ, were developed by forcing an exponential regression equation through several points, including average and theoretical maximum estimates of *Rp* and *Yp*.

The class-specific empirical constants developed are as follows:

Exposed produce	—	0.0324
Leafy vegetables	—	0.0846
Silage	—	0.769

Belcher, G.D., and C.C. Travis. 1989. "Modeling Support for the RURA and Municipal Waste Combustion Projects: Final Report on Sensitivity and Uncertainty Analysis for the Terrestrial Food Chain Model." Interagency Agreement No. 1824-A020-A1, Office of Risk Analysis, Health and Safety Research Division, Oak Ridge National Laboratory. Oak Ridge, Tennessee. October.

This document recommends *Tp* values based on the average period between successive hay harvests and successive grazing.

Bidleman, T.F. 1988. "Atmospheric Processes." *Environmental Science and Technology.* Volume 22. Pages 361-367. November 4.

This document is cited by U.S. EPA (1994a) and NC DEHNR (1997) as the source of the following equations for calculating F_v. For discussion, see References and Discussion, Table B-1-1.

Chamberlain, A.C. 1970. "Interception and Retention of Radioactive Aerosols by Vegetation." *Atmospheric Environment.* 4:57 to 78.

Experimental studies of pasture grasses identified a correlation between initial *Rp* values and productivity (standing crop biomass [*Yp*]):

$$Rp = 1 - e^{-\gamma \cdot Yp}$$

where

γ = Empirical constant; range provided as 2.3 to 3.3
Yp = Yield or standing crop biomass (productivity) (kg DW/m^2)

Hoffman, F.O., K.M. Thiessen, M.L. Frank, and B.G. Blaylock. 1992. "Quantification of the Interception and Initial Retention of Radioactive Contaminants Deposited on Pasture Grass by Simulated Rain." *Atmospheric Environment.* Vol. 26A. 18:3313 to 3321.

This document developed values for a parameter (*r*) that it termed "interception fraction," based on a study in which soluble gamma-emitting radionuclides and insoluble particles tagged with gamma-emitting radionuclides were deposited onto pasture grass (specifically, a combination of fescues, clover, and old field vegetation, including fescue) via simulated rain. The parameter, *r*, is defined as "the fraction of material in rain intercepted by vegetation and initially retained" or, essentially, the product of *Rp* and *Fw,* as defined for the HHRAP:

$$r = Rp \cdot Fw$$

Experimental *r* values obtained include the following:

- A range of 0.006 to 0.3 for anions (based on the soluble radionuclide iodide-131 [^{131}I]); when calculating *Rp* values for anions, U.S. EPA (1994a) used the highest geometric mean *r* value (0.08) observed in the study.
- A range of 0.1 to 0.6 for cations (based on the soluble radionuclide beryllium-7 [7Be]; when calculating *Rp* values for cations, U.S. EPA (1994a) used the highest geometric mean *r* value (0.28) observed in the study.
- A geometric range of values from 0.30 to 0.37 for insoluble polystyrene microspheres (IPM) ranging in diameter from 3 to 25 micrometers, labeled with cerium-141 [^{141}Ce], [^{95}N]b, and strontium-85 ^{85}Sr; when calculating *Rp* values for organics (other than three organics that ionize to anionic forms: 4-chloroaniline, n-nitrosodiphenylamine, and n-nitrosodi-n-propylamine [see Appendix A-3]), U.S. EPA (1994a) used the geometric mean *r* value for IPM with a diameter of 3 micrometers; however, no rationale for this selection was provided.

The authors concluded that, for the soluble ^{131}I anion, interception fraction *r* is an inverse function of rain amount, whereas for the soluble cation ^{7}Be and the IPMs, *r* depends more on biomass than on amount of rainfall. The authors also concluded that (1) the anionic ^{131}I is essentially removed with the water after the vegetation surface has become saturated, and (2) the cationic ^{7}Be and the IPMs are adsorbed to or settle out onto the plant surface. This discrepancy between the behavior of the anionic and cationic species is consistent with a negative charge on the plant surface.

As summarized in U.S. EPA (1994a), this document is the source of the recommended F_v value of 0.27 for dioxins (polychlorinated dibenzodioxins/polychlorinated dibenzofurans [*PCDD/PCDF*]). This value is intended to represent 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) equivalents (TEQ) by weighting all dioxin and furan congeners with nonzero toxicity equivalency factors (TEF). U.S. EPA is investigating the appropriateness of the use of recommended F_v value for *PCDD/PCDFs*.

Junge, C.E. 1977. *Fate of Pollutants in Air and Water Environments, Part I.* Suffet, I.H., Ed. Wiley. New York. Pages 7-26.

Miller, C.W. and F.O. Hoffman. 1983. "An Examination of the Environmental Half-Time for Radionuclides Deposited on Vegetation." *Health Physics.* 45 (3): 731 to 744.

This document is the source of the equation used to calculate *kp*:

$$kp = (\ln 2 / t_{1/2}) \cdot 365 \text{ days/year}$$

where

$t_{1/2}$ = half-time (days)

The study reports half-time values ranging from 2.8 to 34 days for a variety of COPCs on herbaceous vegetation. These half-time values result in calculate *kp* values from 7.44 to 90.36 yr^{-1}.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This is one of the source documents for the equation in Table B-2-7.

Shor, R.W., C.F. Baes, and R.D. Sharp. 1982. *Agricultural Production in the United States by County: A Compilation of Information from the 1974 Census of Agriculture for Use in Terrestrial Food-Chain Transport and Assessment Models.* Oak Ridge National Laboratory Publication. ORNL-5786.

This document is the source of the equation used to calculate *Yp*:

$$Yp \approx P_i = Yh_i / Ah_i$$

where

P_i = productivity of *i*th crop (kilogram dry weight [kg DW]/square meter [m^2])
Yh_i = harvest yield of *i*th crop (kg DW)
Ah_i = area planted to crop *I* (m_2)

using the following information:

Produce Category	Empirical Constant (unitless)	*Rp* (unitless)	*Yp* (kg DW/m^2)	*Yp* (kg WW/m^2)	Intake (g/kg-day)
Exposed Fruits	0.0324	0.053	0.252	1.68	0.19
Exposed Vegetables	--	0.982	5.660	89.4	0.11
Leafy Vegetables	0.0846	0.215	0.246	2.86	--
Fruiting Vegetables	0.0324	0.996	10.52	167	--

The use of the empirical relationship developed by Baes, Sharp, Sjoreen, and Shor (1984) to estimate *Rp* based on *Yp* requires that *Yp* term to be in whole-weight units. However, in Equation B-2-7, the *Yp* term should be in dry-weight units.

For exposed vegetables, *Rp* was derived from a weighted average of leafy vegetable and fruiting vegetable *Rp* values. This weighted average was based on whole-weight *Yp* values for leafy and fruiting vegetables. In addition, the exposed vegetable *Yp* value, both whole- and dry-weight, was derived by the following:

$$Yp_{Exposed\ Vegetables} = \frac{Yh_{Leafy\ Vegetables} + Yh_{Fruiting\ Vegetables}}{Ah_{Leafy\ Vegetables} + Ah_{Fruiting\ Vegetables}}$$

The following produce items were included in each category:

Exposed Fruits—apple, apricot, berry, cherry, cranberry, grape, peach, pear, plum/prune, strawberry
Exposed Vegetables—asparagus, cucumber, eggplant, sweet pepper, tomato, snap beans, broccoli, brussel sprouts, cauliflower, celery, lettuce, and spinach

The ingestion rates for exposed fruits and exposed vegetables were based on U.S. EPA (1997), homegrown intake rates.

However, U.S. EPA has reviewed Baes, Sharp, Sjoreen, and Shor (1984), which also presents and discusses this equation.

U.S. Department of Agriculture (USDA). 1994a. *Vegetables 1993 Summary.* National Agricultural Statistics Service, Agricultural Statistics Board. Washington, D.C. Vg 1-2 (94).

USDA. 1994b. *Noncitrus Fruits and Nuts 1993 Summary.* National Agricultural Statistics Service, Agricultural Statistics Board, Washington, D.C. Fr Nt 1-3 (94).

One of the sources of *Yh* (harvest yield) and *Ah* (area planted for harvest) values for fruits, fruiting vegetables, legumes, and leafy vegetables used to calculate *Yp* (yield or standing crop biomass). *Yh* values were converted (for use in the equations) to dry weight by using average conversion factors for these same aboveground produce classes, as presented in Baes, Sharp, Sjoreen, and Shor (1984). The fruits and vegetables considered in each category are as follows:

Exposed fruits—apple, apricot, berry, cherry, cranberry, grape, peach, pear, plum/prune,and strawberry
Exposed vegetables—asparagus, cucumber, eggplant, sweet pepper, tomato, snap beans, broccoli, brussel sprouts, cauliflower, celery, lettuce, and spinach

U.S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600/6-90/003. January.

This is one of the source documents for the equation in Table B-2-7. This document also states that the best estimate of *Yp* (yield or standing crop biomass) is productivity, as defined under Shor, Baes, and Sharp (1982).

U.S. EPA. 1992. *Technical Support Document for Land Application of Sewage Sludge*, Volumes I and II. Office of Water. Washington, D.C. EPA 822/R-93-001a.

This document is the source of ingestion rates (g DW/day) for aboveground produce classes—fruiting vegetables (4.2), leafy vegetables (2.0), and legumes (8.8)—used to calculate *Rp* and *Yp*.

U.S. EPA. 1993. *Review Draft Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Office of Health and Environmental Assessment. Office of Research and Development. EPA/600/AP-93/003. November.

This is one of the source documents for the equation in Table B-2-7.

U.S. EPA. 1994a. *Estimating Exposure to Dioxin-Like Compounds. Volume III: Site-Specific Assessment Procedures.* External Review Draft. Office of Research and Development. Washington, D.C. EPA/600/6-88/005Cc. June.

This is the source of ingestion rate for fruits, based on whole weight (88 g/day) and converted to dry weight by using an average whole-weight to dry-weight conversion factor for fruits (excluding plums/prunes, which had an extreme value) of 0.15 taken from Baes, Sharp, Sjoreen, and Shor (1984), used to calculate *Rp* and *Yp*.

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This is one of the source documents for the equation in Table B-2-7.

This document also recommended weighted average *Rp* and *Yp* values of 0.05 and 1.6, respectively, based on the empirical relationships identified by Chamberlain (1970) and Shor, Baes, and Sharp (1982).

$$Rp = 1 - e^{-\gamma \cdot Yp}$$

where

γ = Empirical constant; range provided as 2.3 to 3.3
Yp = Standing crop biomass (productivity) (kg DW/m^2)

and Shor, Baes, and Sharp (1982):

$$Yp = Yh_i / Ah_i$$

where

Yh_i = Harvest yield of *i*th crop (kg DW)
Ah_i = Area planted to crop *I* (m^2)

U.S. EPA. 1995. *Review Draft Development of Human Health-Based and Ecologically-Based Exit Criteria for the Hazardous Waste Identification Project.* Volumes I and II. Office of Solid Waste. March 3.

This is one of the source documents for the equation in Table B-2-7.

U.S. EPA. 1997. *Exposure Factors Handbook.* Office of Research and Development. EPA/600/P-95/002F. August.

This document is the source of relative ingestion rates.

Description
This equation calculates the COPC concentration in aboveground produce resulting from wet and dry deposition of COPCs onto plant surfaces. The limitations and uncertainty introduced in calculating this value include the following: (1) The range of values for the variable *Bv* (air-to-plant biotransfer factor) is about 19 orders of magnitude for organic COPCs (this range may change on the basis of the tables in Appendix A-3). COPC-specific *Bv* values for nondioxin-like compounds may be overestimated by up to one order of magnitude, based on experimental conditions used to develop the algorithm used to estimate *Bv* values. (2) The algorithm used to calculate values for the variable F_v assumes a default value for the parameter S_T (Whitby's average surface area of particulates [aerosols]) of background plus local sources, rather than an S_T value for urban sources. If a specific site is located in an urban area, the use of the latter S_T value may be more appropriate. The S_T value for urban sources is about one order of magnitude greater than that for background plus local sources and would result in a lower F_v value; however, the F_v value is likely to be only a few percent lower. As highlighted by uncertainties described above, *Pv* is most affected by the value calculated for *Bv*.

ABOVEGROUND PRODUCE CONCENTRATION DUE TO AIR-TO-PLANT TRANSFER (CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Equation

$$Pv = Q \cdot F_v \cdot \frac{Cyv \cdot Bv_{ag} \cdot VG_{ag}}{\rho_a}$$

For mercury modeling

$$Pv = (0.48Q) \cdot F_v \cdot \frac{Cyv \cdot Bv_{ag} \cdot VG_{ag}}{\rho_a}$$

Use *0.48Q* for total mercury and $F_v = 0.85$ in the mercury modeling equation to calculate *Pv*. The calculated *Pv* value is apportioned into the divalent mercury (Hg^{2+}) and methyl mercury (MHg) forms based on the 78% Hg^{2+} and 22% MHg speciation split in abovegroundproduce.

$Pv\ (Hg^{2+})$ = 0.78 *Pv*
Pv (Mhg) = 0.22 *Pv*

Evaluate divalent and methyl mercury as individual COPCs. Calculate *Pv* for divalent and methyl mercury using the corresponding values.

Variable	Description	Units	Value
Pv	Concentration of COPC in aboveground produce due to air-to-plant transfer	µg COPC/g DW (equivalent to mg COPC/kg DW)	
Q	COPC-specific emission rate	g/s	**Varies** This variable is COPC- and site-specific, and is determined by air dispersion modeling. See Chapters 2 and 3 of the HHRAP for guidance regarding the calculation of this variable. Uncertainties associated with this variable are site-specific.

TABLE B-2-8

ABOVEGROUND PRODUCE CONCENTRATION DUE TO AIR-TO-PLANT TRANSFER
(CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Variable	Description	Units	Value
F_v	Fraction of COPC air concentration in vapor phase	unitless	**0 to 1** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values is presented in Appendix A-3. This range is based on values presented in Appendix A-3. Values are also presented in U.S. EPA (1994b) and NC DEHNR (1997). F_v was calculated using an equation presented in Junge (1977) for all organic COPCs, including PCDDs and PCDFs. U.S. EPA (1994c) states that $F_v = 0$ for all metals (except mercury). The following uncertainties are associated with this variable: (1) It is based on the assumption of a default S_T value for background plus local sources, rather than an S_T value for urban sources. If a specific site is located in an urban area, the use of the latter S_T value may be more appropriate. Specifically, the S_T value for urban sources is about one order of magnitude greater than that for background plus local sources, and it would result in a lower calculated F_v value; however, the F_v value is likely to be only a few percent lower. (2) According to Bidleman (1988), the equation used to calculate F_v assumes that the variable *c* (Junge constant) is constant for all chemicals; however, the value of *c* depends on the chemical (sorbate) molecular weight, the surface concentration for monolayer coverage, and the difference between the heat of desorption from the particle surface and the heat of vaporization of the liquid phase sorbate. To the extent that site- or COPC-specific conditions may cause the value of *c* to vary, uncertainty is introduced if a constant value of *c* is used to calculate F_v.
Cyv	Unitized yearly average air concentration from vapor phase	µg-s/g-m^3	**Varies** This variable is COPC- and site-specific, and is determined by air dispersion modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.
Bv_{ag}	COPC air-to-plant biotransfer factor for aboveground produce	unitless ([mg COPC/g DW plant]/[(mg COPC/g air])	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. Uncertainty associated with this variable include the following: (1) The studies that formed the basis of the algorithm used to estimate *Bv* values were conducted on azalea leaves and grasses, and may not accurately represent *Bv* for aboveground produce other than leafy vegetables.

Variable	Description	Units	Value
VG_{ag}	Empirical correction factor for aboveground produce	unitless	**0.01 or 1.0** U.S. EPA OSW recommends that a VG_{ag} value of 0.01 for COPCs with a log K_{ow} greater than 4 and a value of 1.0 for COPCs with a log K_{ow} less than 4. This variable is an empirical correction factor that reduces aboveground produce concentration. The equation in this table was developed to estimate the transfer of COPCs into leafy vegetation rather than into bulkier aboveground produce, such as apples. Because of the protective outer skin, size, and shape of bulky produce, transfer of lipophilic COPCs (log K_{ow} greater than 4) to the center of the produce is not likely. In addition, typical preparation techniques, such as washing, peeling, and cooking, will further reduce residues. U.S. EPA (1994b) recommended a value of 0.01, based on U.S. EPA (1994a), but made no distinction between fruits, vegetables, and leafy vegetation. NC DEHNR (1997), also citing U.S. EPA (1994a), recommends values of (1) 0.01 for fruits and fruiting vegetables, and (2) 1.0 for leafy vegetables. The values cited from U.S. EPA (1994a) are also based on information from Riederer (1990) and Wipf, Homberger, Neuner, Ranalder, Vetter, and Vuilleumier (1982). Uncertainties associated with this variable include the following: (1) U.S. EPA (1994a) assumes an insignificant translocation of compounds deposited on the surface of aboveground vegetation to inner parts of aboveground produce. This may underestimate *Pv*. (2) U.S. EPA (1994a) assumes that the density of the skin and the whole vegetable are equal. This may overestimate *Pv*. (3) U.S. EPA (1994a) assumes that the thickness of vegetable skin and broadleaf tree skin are equal. The effect of this assumption of *Pv* is unknown.
ρ_a	Density of air	g/m^3	**1200.0** U.S. EPA OSW recommends the use of this value based on Weast (1986). This reference indicates that air density varies with temperature. The density of air at both 20°C and 25°C (rounded to two significant figures) is $1.2 \times 10^{+3}$. U.S. EPA (1990) also recommends this value, but states that is was based on a temperature of 25°C. U.S. EPA (1994b) and NC DEHNR (1997) recommend this same value but state that it was calculated at standard conditions (20°C and 1 atmosphere). Both documents cite Weast (1981).

REFERENCES AND DISCUSSION

Bidleman, T.F. 1988. "Atmospheric Processes." *Environmental Science and Technology*. Volume 22. Number 4. Pages 361-367.

For discussion, see References and Discussion in Table B-1-1.

This is the reference for the statement that the equation used to calculate the fraction of air concentration in vapor phase (F_v) assumes that the variable *c* (the Junge constant) is constant for all chemicals. However, this reference notes that the value of *c* depends on the chemical (sorbate) molecular weight, the surface concentration for monolayer coverage, and the difference between the heat of desorption from the particle surface and the heat of vaporization of the liquid-phase sorbate.

Junge, C.E. 1977. *Fate of Pollutants in Air and Water Environments, Part I.* Suffet, I.H., Ed. Wiley. New York. Pages 7-26.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This is one of the source documents for the equation in Table B-2-8. This document also recommends that (1) F_v values be based on the work of Bidleman (1988), and (2) an empirical correction factor (VG_{ag}) be used to reduce concentrations of COPCs in specific vegetation types—specifically, a VG_{ag} value of 0.5 is recommended for silage. However, no rationale is provided for this value. This factor is used to reduce estimated COPC concentrations in specific vegetation types, because (1) *Bv* was developed for azalea leaves, and (2) it is assumed that there is insignificant translocation of compounds deposited on the surface of some vegetation types to the inner parts of this vegetation because of the lipophilicity of the COPC.

Riederer, M. 1990. "Estimating Partitioning and Transport of Organic Chemicals in the Foliage/Atmosphere System: Discussion of a Fugacity-Based Model." *Environmental Science and Technology*. 24: 829 to 837.

This is the source of the leaf thickness estimate used to estimate the empirical correction factor (VG_{ag}).

U.S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA-600-90-003. January.

This document is a source of air density values.

U.S. EPA. 1993. *Review Draft Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Office of Health and Environmental Assessment. Office of Research and Development. EPA-600-AP-93-003. November 10.

Based on attempts to model background concentrations of dioxin-like compounds in beef on the basis of known air concentrations, this document recommends reducing, by a factor of 10, *Bv* values calculated by using the Bacci, Cerejeira, Gaggi, Chemello, Calamari, and Vighi (1992) algorithm The use of this factor "made predictions [of beef concentrations] come in line with observations."

U.S. EPA. 1994a. *Estimating Exposure to Dioxin-Like Compounds. Volume II: Properties, Sources, Occurrence, and Background Exposures.* External Review Draft. Office of Research and Development. Washington, DC. EPA/600/6-88/005Cc. June.

ABOVEGROUND PRODUCE CONCENTRATION DUE TO AIR-TO-PLANT TRANSFER (CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

This document recommends an empirical correction factor of 0.01 to reduce estimated vegetable concentrations on the basis of the assumption that there is insignificant translocation of compounds deposited on the surface of aboveground vegetation to inner parts for aboveground produce. The document provides no reference or discussion regarding the validity of this assumption.

The factor of 0.01 is based on a similar correction factor for belowground produce (VG_{bg}), which is estimated on the basis of a ratio of the vegetable skin mass to vegetable total mass. The document assumes that the densities of the skin and vegetable are equal. The document also assumes an average vegetable skin leaf that is based on Rierderer (1990). Based on these assumptions, U.S. EPA (1994a) calculated VG_{bg} for carrots and potatoes of 0.09 and 0.03, respectively. By comparing these values to contamination reduction research completed by Wipf, Homberger, Neuner, Ranalder, Vetter, and Vuilleumier (1982), U.S. EPA (1994a) arrived at the recommended VG_{ag} value of 0.01.

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This is one of the source documents for the equation in Table B-2-8. This document also presents a range (0.27 to 1) of F_v values for organic COPCs, based on the work of Bidleman (1988); F_v for all inorganics is set equal to zero.

U.S. EPA. 1995. *Review Draft Development of Human Health-Based and Ecologically-Based Exit Criteria for the Hazardous Waste Identification Project.* Volumes I and II. Office of Solid Waste. March 3.

U.S. EPA. 1997. Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment. Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

Weast, R.C. 1981. *Handbook of Chemistry and Physics.* 62nd Edition. Cleveland, Ohio. CRC Press.

This document is a reference for air density values.

Weast, R.C. 1986. *Handbook of Chemistry and Physics.* 66th Edition. Cleveland, Ohio. CRC Press.

This document is a reference for air density values, and is an update of Weast (1981).

Wipf, H.K., E. Homberger, N. Neuner, U.B. Ranalder, W. Vetter, and J.P. Vuilleumier. 1982. "TCDD Levels in Soil and Plant Samples from the Seveso Area." *In: Chlorinated Dioxins and Related Compounds: Impact on the Environment.* Eds. Hutzinger, O. et al. Pergamon, NY.

TABLE B-2-9

ABOVEGROUND PRODUCE CONCENTRATION DUE TO ROOT UPTAKE (CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Description

This equation calculates the COPC concentration in aboveground produce due to direct uptake of COPCs from soil through plant roots. The limitations and uncertainty introduced in calculating this value include the following:

(1) The availability of site-specific information, such as meteorological data, will affect the accuracy of *Cs* estimates.

(2) Estimated COPC-specific soil-to-plant bioconcentration factors (*Br*) do not reflect site-specific conditions. This may be especially true for inorganic COPCs for which estimates of *Br* would be more accurately estimated by using site-specific *BCFs* rather than *BCF*s presented in Baes, Sharp, Sjoreen, and Shor (1984). Hence, U.S. EPA OSW recommends the use of plant uptake response slope factors derived in U.S. EPA (1992) for arsenic, cadmium, selenium, nickel, and zinc.

Equation

$$Pr_{ag} = Cs \cdot Br_{ag}$$

For mercury modeling, aboveground produce concentration due to root uptake is calculated using the respective *Cs* and *Br* values for divalent mercury (Hg^{2+}) and methyl mercury (MHg).

$$Pr_{ag(Hg^{2+})} = Cs_{Hg^{2+}} \cdot Br_{ag(Hg^{2+})}$$

$$Pr_{ag(MHg)} = Cs_{MHg} \cdot Br_{ag(MHg)}$$

Variable	Description	Units	Value
Pr_{ag}	Concentration of COPC in aboveground produce due to root uptake	mg COPC/kg DW	
Cs	Average soil concentration over exposure duration	mg COPC/kg soil	**Varies** This value is COPC-and site-specific and should be calculated using the equation in Table B-2-1. Uncertainties associated with this variable are site-specific.

TABLE B-2-9

ABOVEGROUND PRODUCE CONCENTRATION DUE TO ROOT UPTAKE (CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

Variable	Description	Units	Value
Br_{ag}	Plant-soil bioconcentration factor for aboveground produce	unitless ([mg COPC/kg DW plant]/[mg COPC/ kg soil])	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. Uncertainties associated with this variable include the following: (1) Estimates of *Br* for some inorganic COPCs, based on plant uptake response slope factors, may be more accurate than those based on *BCF*s from Baes, Sharp, Sjoreen, and Shor (1984). (2) U.S. EPA OSW recommends that uptake of organic COPCs from soil and transport of the COPCs to aboveground plant parts be calculated on the basis of a regression equation developed in a study of the uptake of 29 organic compounds. This regression equation, developed by Travis and Arms (1988), may not accurately represent the behavior of all organic COPCs under site-specific conditions.

REFERENCES AND DISCUSSION

Baes, C.F., R.D. Sharp, A.L. Sjoreen, and R.W. Shor. 1984. *Review and Analysis of Parameters and Assessing Transport of Environmentally Released Radionuclides through Agriculture.* ORNL-5786. Oak Ridge National Laboratory. Oak Ridge, Tennessee. September.

Element-specific bioconcentration factors (*BCF*) were developed by Baes, Sharp, Sjoreen, and Shor (1984)—for both vegetative (stems and leaves) portions of food crops *(Bv)* and nonvegetative (reproductive—fruits, seeds, and tubers) portions of food crops (*Br*)—on the basis of a review and compilation of a wide variety of measured, empirical, and comparative data. Inorganic-specific *Br* values were calculated as a weighted average of vegetative (*Bv*) and reproductive (*Br*) *BCF*s. U.S. EPA recommends that inorganic-specific *Br* values be calculated as a weighted average of vegetative and reproductive BCFs. Relative ingestion rates determined from U.S. EPA (1997a) are 75 percent reproductive and 25 percent vegetative for homegrown produce. However, for exposed fruits only the reproductive BCFs should be used.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This is one of the source documents for the equation in Table B-2-9.

Travis, C.C. and A.D. Arms. 1988. "Bioconcentration of Organics in Beef, Milk, and Vegetation." *Environmental Science and Technology.* 22:271 to 274.

Based on paired soil and plant concentration data for 29 organic compounds, this document developed a regression equation relating soil-to-plant *BCF* (*Br*) to K_{ow};

$$\log Br = 1.588 - 0.578 \log K_{ow}$$

U.S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600/6-90/003. January.

This is one of the source documents for the equation in Table B-2-9.

U.S. EPA. 1992. *Technical Support Document for Land Application of Sewage Sludge,* Volumes I and II. Office of Water. Washington, D.C. EPA 822/R-93-001a.

Source of plant uptake response factors for arsenic, cadmium, nickel, selenium, and zinc. Plant uptake response factors are converted to BCFs by multiplying the plant uptake response factor by 2.

U.S. EPA. 1994. *Estimating Exposure to Dioxin-Like Compounds. Volume III: Site-Specific Assessment Procedures.* External Review Draft. Office of Research and Development. Washington, D.C. EPA/600/6-88/005Cc. June.

This is the source for ingestion rate for fruits, based on whole weight (88 g/day), and converted to dry weight by using an average whole-weight to dry-weight conversion factor for fruits (excluding plums/prunes, which had an extreme value) of 0.15 from Baes, Sharp, Sjoreen, and Shor (1984)—used to calculate *Br*.

U.S. EPA. 1995. *Review Draft Development of Human Health-Based and Ecologically-Based Exit Criteria for the Hazardous Waste Identification Project.* Volumes I and II. Office of Solid Waste. March 3.

ABOVEGROUND PRODUCE CONCENTRATION DUE TO ROOT UPTAKE (CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)

This document recommends using the *BCFs*, *Bv*, and *Br* from Baes, Sharp, Sjoreen, and Shor (1984) for calculating the uptake of inorganics into vegetative growth (stems and leaves) and nonvegetative growth (fruits, seeds, and tubers), respectively.

Although most *BCFs* used in this document come from Baes, Sharp, Sjoreen, and Shor (1984), values for some inorganics were apparently obtained from plant uptake response slope factors. These uptake response slope factors derived from U.S. EPA (1992).

U.S. EPA. 1997a. *Exposure Factors Handbook.* Office of Research and Development. EPA/600/P-95/002F. August.

This document is the source for relative intake rate split of 75 percent reproductive and 25 percent vegetative for homegrown produce.

U.S. EPA. 1997b. Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment. Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

BELOWGROUND PRODUCE CONCENTRATION DUE TO ROOT UPTAKE (CONSUMPTION OF BELOWGROUND PRODUCE EQUATIONS)

Description

This equation calculates the COPC concentration in belowground vegetation due to direct uptake of COPCs from soil. The limitations and uncertainty introduced in calculating this value include the following:

(1) The availability of site-specific information, such as meteorological data, will affect the accuracy of *Cs* estimates.
(2) Estimated COPC-specific soil-to-plant biotransfer factors (*Br*) not reflect site-specific conditions. This may be especially true for inorganic COPCs for which estimates of *Br* would be more accurately estimated by using site-specific BCFs from Baes, Sharp, Sjoreen, and Shor (1984). Hence, for arsenic, cadmium, selenium, nickel, and zinc, U.S. EPA OSW recommends the use of plant uptake response slope factors derived from U.S. EPA (1992).

$$Pr_{bg} = Cs \cdot Br_{rootveg} \cdot VG_{rootveg}$$

$$Br_{rootveg} = \frac{RCF}{Kd_s}$$

For mercury modeling, belowground produce concentration due to root uptake is calculated using the respective *Cs* and *Br* values for divalent mercury (Hg^{2+}) and methyl mercury (MHg).

Variable	Description	Units	Value
Pr_{bg}	Concentration of COPC in belowground produce due to root uptake	mg COPC/kg DW	
Cs	Average soil concentration over exposure duration	mg COPC/kg soil	**Varies** This value is COPC-and site-specific and should be calculated using the equation in Table B-2-1. Uncertainties associated with this variable are site-specific.

BELOWGROUND PRODUCE CONCENTRATION DUE TO ROOT UPTAKE (CONSUMPTION OF BELOWGROUND PRODUCE EQUATIONS)

Variable	Description	Units	Value
$Br_{rootveg}$	Plant-soil bioconcentration factor for belowground produce	unitless ([mg COPC/kg plant DW]/[mg COPC/ kg soil])	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. Uncertainties associated with this variable include the following: (1) Estimates of *Br* for some inorganic COPCs, based on plant uptake response slope factors, may be more accurate than those based on BCFs from Baes, Sharp, Sjoreen, and Shor (1984). (2) U.S. EPA OSW recommends that uptake of organic COPCs from soil and the transport of COPCs to belowground produce be calculated on the basis of a regression equation developed by Briggs et al (1982). This regression equation may not accurately represent the behavior of all classes of organic COPCs under site-specific conditions.

Variable	Description	Units	Value
$VG_{rootveg}$	Empirical correction factor for belowground produce	unitless	**0.01 or 1.0** U.S. EPA OSW recommends that a $VG_{rootveg}$ value of 0.01 be used for COPCs with a log K_{ow} greater than 4 and that a $VG_{rootveg}$ value of 1.0 be used for COPCS with a log K_{ow} less than 4. This variable is an empirical correction factor that reduces produce concentration. Because of the protective outer skin, size, and shape of bulky produce, transfer of lipophilic COPCs (log K_{ow} greater than 4) to the center of the produce is not likely. In addition, typical preparation techniques, such as washing, peeling, and cooking, will further reduce residues. U.S. EPA (1994) recommended a $VG_{rootveg}$ value of 0.01 for lipophilic COPCs (log K_{ow} greater than 4) to reduce estimated belowground produce concentrations. This estimate for unspecified vegetables is based on: $$VG_{rootveg} = \frac{M_{skin}}{M_{vegetable}}$$ where M_{skin} = Mass of thin (skin) layer of an below ground vegetable (g) $M_{vegetable}$ = Mass of entire vegetable (g) If it is assumed that the density of the skin and the whole vegetable are the same, this equation can become a ratio of the volume of the skin to that of the whole vegetable. With this assumption, U.S. EPA (1994) calculated $VG_{rootveg}$ values of 0.09 and 0.03 for carrots and potatoes, respectively. U.S. EPA (1994) identified other processes, such as peeling, cooking, and cleaning, that will further reduce the vegetable concentration. Because of these other processes, U.S. EPA recommended a $VG_{rootveg}$ value of 0.01 for lipophilic COPCs. The following uncertainty is associated with this variable: U.S. EPA (1994) assumes that the density of the skin and the whole vegetable are equal. This may overestimate *Pr*. However, based on the limited range of $VG_{rootveg}$ (compared to *Br*), it appears that in most cases, these uncertainties will have a limited impact on the calculation of *Pr* and, ultimately, risk.

TABLE B-2-10

BELOWGROUND PRODUCE CONCENTRATION DUE TO ROOT UPTAKE (CONSUMPTION OF BELOWGROUND PRODUCE EQUATIONS)

Variable	Description	Units	Value
Kd_s	Soil-water partition coefficient	cm^3 water/g soil	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Uncertainties associated with this parameter will be limited if Kd_s values are calculated as described in Appendix A-3.

REFERENCES AND DISCUSSION

Baes, C.F., R.D. Sharp, A.L. Sjoreen, and R.W. Shor. 1984. *Review and Analysis of Parameters and Assessing Transport of Environmentally Released Radionuclides through Agriculture.* ORNL-5786. Oak Ridge National Laboratory. Oak Ridge, Tennessee. September.

For discussion, see References and Discussion in Table B-2-10.

Briggs, G.G., R.H. Bromilow, and A.A. Evans. 1982. Relationships between lipophilicity and root uptake and translocation of non-ionized chemicals by barley. *Pesticide Science* 13:495-504.

This document presents the relationship between *RCF* and K_{ow} presented in the equation in Table B-2-10..

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This is a source document for the equation in Table B-2-10.

Travis, C.C. and A.D. Arms. 1988. "Bioconcentration of Organics in Beef, Milk, and Vegetation." *Environmental Science and Technology.* 22:271 to 274.

Based on paired soil and plant concentration data for 29 organic compounds, this document developed a regression equation relating soil-to-plant *BCF* (*Br*) to K_{ow}

$$\log Br = 1.588 - 0.578 \log K_{ow}$$

U.S. EPA. 1992. *Technical Support Document for Land Application of Sewage Sludge*, Volumes I and II. Office of Water. Washington, D.C. EPA 822/R-93-001a.

Source of plant uptake response factors for arsenic, cadmium, nickel, selenium, and zinc. Plant uptake response factors are converted to BCFs by multiplying the plant uptake response factor by 2.

U.S. EPA. 1993. *Review Draft Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Office of Health and Environmental Assessment. Office of Research and Development. EPA-600-AP-93-003. November 10.

This document is a source of COPC-specific Kd_s values.

U.S. EPA. 1994. *Estimating Exposure to Dioxin-Like Compounds. Volume III: Site-Specific Assessment Procedures.* External Review Draft. Office of Research and Development. Washington, D.C. EPA/600/6-88/005Cc. June.

This is a source document for $Vg_{rootveg}$ values.

U.S. EPA. 1995. *Review Draft Development of Human Health-Based and Ecologically-Based Exit Criteria for the Hazardous Waste Identification Project.* Volumes I and II. Office of Solid Waste. March 3.

This document recommends using the *BCFs*, *Bv*, and *Br* from Baes, Sharp, Sjoreen, and Shor (1984) for calculating the uptake of inorganics into vegetative growth (stems and leaves) and nonvegetative growth (fruits, seeds, and tubers), respectively.

TABLE B-2-10

BELOWGROUND PRODUCE CONCENTRATION DUE TO ROOT UPTAKE (CONSUMPTION OF BELOWGROUND PRODUCE EQUATIONS)

Although most *BCFs* used in this document come from Baes, Sharp, Sjoreen, and Shor (1984), values for some inorganics were apparently obtained from plant uptake response slope factors. These uptake response slope factors were calculated from field data, such as metal methodologies. References used to calculate the uptake response slope factors are not clearly identified.

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

SOIL CONCENTRATION DUE TO DEPOSITION (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Description

The equations in this table are used to calculate an average COPC soil concentration resulting from wet and dry deposition of particles and vapors to soil over the exposure duration. COPCs are assumed to be incorporated only to a finite depth (the soil mixing zone depth, Z_s).

The COPC soil concentration averaged over the exposure duration, represented by Cs, should be used for carcinogenic COPCs, where the risk is averaged over the lifetime of an individual. Because the hazard quotient associated with noncarcinogenic COPCs is based on a reference dose rather than a lifetime exposure, the highest annual average COPC soil concentration occurring during the exposure duration period should be used for noncarcinogenic COPCs. The highest annual average COPC soil concentration would occur at the end of the time period of combustion and is represented by Cs_{tD}.

The following uncertainties are associated with this variable:

(1) The time period for deposition of COPCs resulting from hazardous waste combustion is assumed to be a conservative, long-term value. This assumption may overestimate Cs and Cs_{tD}.

(2) Exposure duration values (T_2) are based on historical mobility studies and will not necessarily remain constant. Specifically, mobility studies indicate that most receptors that move remain in the vicinity of the combustion unit; however, it is impossible to accurately predict the probability that these short-distance moves will influence exposure, based on factors such as atmospheric transport of pollutants.

(3) The use of a value of zero for T_1 does not account for exposure that may have occurred from historic operations and emissions from hazardous waste combustion. This may underestimate Cs and Cs_{tD}.

(4) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils and, resulting a greater mixing depth. This uncertainty may overestimate Cs and Cs_{tD}.

(5) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate Cs and Cs_{tD}.

TABLE B-3-1

SOIL CONCENTRATION DUE TO DEPOSITION
(CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

(Page 2 of 11)

Equation for Carcino*gens

Soil Concentration Averaged Over Exposure Duration

$$Cs = \frac{\left(\frac{Ds \cdot tD - Cs_{tD}}{ks}\right) + \left(\frac{Cs_{tD}}{ks} \cdot [1 - \exp(-ks\,(T_2 - tD))]\right)}{(T_2 - T_1)} \quad for\ T_1 < tD < T_2$$

$$Cs = \frac{Ds}{ks \cdot (tD - T_1)} \cdot \left(\left[tD + \frac{\exp(-ks \cdot tD)}{ks} \right] - \left[T_1 + \frac{\exp(-ks \cdot T_1)}{ks} \right] \right) \quad for\ T_2 \leq tD$$

Equation for Noncarcinogens

Highest Annual Average Soil Concentration

$$Cs_{tD} = \frac{Ds \cdot [1 - \exp(-ks \cdot tD)]}{ks}$$

where

$$Ds = \frac{100 \cdot Q}{Z_s \cdot BD} \cdot [F_v \cdot (0.31536 \cdot Vdv \cdot Cyv + Dywv) + (Dydp + Dywp) \cdot (1 - F_v)]$$

For mercury modeling

$$Ds = \frac{100 \cdot (0.48Q)}{Z_s \cdot BD} \cdot [F_v \, (0.31536 \cdot Vdv \cdot Cyv + Dywv) + (Dydp + Dywp) \cdot (1 - F_v)]$$

Use *0.48Q* for total mercury and F_v = 0.85 in the mercury modeling equation to calculate *Ds*. The calculated *Ds* value is apportioned into the divalent mercury (Hg^{2+}) and methyl mercury (MHg) forms based on the assumed 98% Hg^{2+} and 2% MHg speciation split in soils (see Chapter 2). Elemental mercury (Hg^0) occurs in very small amounts in the vapor phase and does not exist in the particle or particle bound phase. Therefore, elemental mercury deposition onto soils is assumed to be negligible or zero. Elemental mercury is evaluated for the direct inhalation pathway only (Table B-5-1).

Ds (Hg^{2+}) = 0.98 *Ds*
Ds (Mhg) = 0.02 *Ds*
Ds (Hg^0) = 0.0

Evaluate divalent and methyl mercury as individual COPCs. Calculate *Cs* for divalent and methyl mercury using the corresponding (1) fate and transport parameters for mercuric chloride (divalent mercury) and methyl mercury provided in Appendix A-3, and (2) *Ds* (Hg^{2+}) and *Ds* (MHg) as calculated above.

Variable	Description	Units	Value
Cs	Average soil concentration over exposure duration	mg COPC/kg soil	

Variable	Description	Units	Value
Cs_{tD}	Soil concentration at time *tD*	mg COPC/kg soil	
Ds	Deposition term	mg COPC/kg soil-yr	**Varies** U.S. EPA (1994a) and NC DEHNR (1991) recommend incorporating the use of a deposition term into the *Cs* equation. Uncertainties associated with this variable include the following: (1) Five of the variables in the equation for *Ds* (*Q*, *Cyv*, *Dywv*, *Dywp*, and *Dydp*) are COPC- and site-specific. Values of these variables are estimated on the basis of modeling. The direction and magnitude of any uncertainties should not be generalized. (2) Based on the narrow recommended ranges, uncertainties associated with *Vdv*, F_v, and *BD* are expected to be low. (3) Values for Z_s vary by about one order of magnitude. Uncertainty is greatly reduced if it is known whether soils are tilled or untilled.
tD	Time period over which deposition occurs (time period of combustion)	yr	**100** U.S. EPA (1990a) specifies that this period of time can be represented by periods of 30, 60 or 100 years. U.S. EPA OSW recommends that facilities use the conservative value of 100 years unless site-specific information is available indicating that this assumption is unreasonable (see Chapter 6 of the HHRAP Protocol).
ks	COPC soil loss constant due to all processes	yr^{-1}	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-3-2. The COPC soil loss constant is the sum of all COPC removal processes. Uncertainty associated with this variable includes the following: COPC-specific values for *ksg* (one of the variables in the equation in Table B-3-2) are empirically determined from field studies. No information is available regarding the application of these values to the site-specific conditions associated with affected facilities.

Variable	Description	Units	Value
T_2	Length of exposure duration	yr	**6, 30, or 40** U.S. EPA OSW recommends the following reasonable maximum exposure (RME) values for T_2: Exposure Duration — RME — Reference Child Resident, Subsistence Farmer Child, Subsistence Fisher Child — 6 years — U.S. EPA (1990b) Adult Resident and Subsistence Fisher — 30 years (6 child and 24 adult) — U.S. EPA (1990b) Subsistence Farmer — 40 years — U.S. EPA (1994b) U.S. EPA (1994c) recommended the following unreferenced values: Exposure Duration — Years Subsistence Farmer — 40 Adult Resident — 30 Subsistence Fisher — 30 Child Resident — 9 Uncertainties associated with this variable include the following: (1) Exposure duration rates are based on historical mobility rates and may not remain constant. This assumption may overestimate or underestimate *Cs* and Cs_{tD}. (2) Mobility studies indicate that most receptors that move remain in the vicinity of the emission sources; however, it is impossible to accurately predict the likelihood that these short-distance moves will influence exposure, based on factors such as atmospheric transport of pollutants. This assumption may overestimate or underestimate *Cs* and Cs_{tD}.
T_1	Time period at the beginning of combustion	yr	**0** Consistent with U.S. EPA (1994bc), U.S. EPA OSW recommends a value of 0 for T_1. The following uncertainty is associated with this variable: The use of a value of 0 for T_1 does not account for exposure that may have occurred from historical operation or emissions from the combustion of hazardous waste. This may underestimate *Cs* and Cs_{tD}.

Variable	Description	Units	Value
100	Units conversion factor	mg-cm²/kg-cm²	
Q	COPC emission rate	g/s	**Varies** This variable is COPC- and site-specific. See Chapters 2 and 3 of the HHRAP for guidance regarding the calculation of this variable. Uncertainties associated with this variable are site-specific.
Z_s	Soil mixing zone depth	cm	**1 to 20** U.S. EPA OSW recommends the following values for this variable: Soil — Depth (cm) — Reference Untilled — 1 — U.S. EPA (1990a) and U.S. EPA (1993a) Tilled — 20 — U.S. EPA (1990a) and U.S. EPA (1993a) U.S. EPA (1990a) does not include a reference for these values. The following uncertainties are associated with this variable: (1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled, resulting a greater mixing depth. This uncertainty may overestimate *Cs* and Cs_{tD}. (2) Deposition to hard surfaces may result in dust residues that have negligible dilution in comparison to that of other residues. This uncertainty may underestimate *Cs* and Cs_{tD}.
BD	Soil bulk density	g soil/cm³ soil	**1.5** This variable is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil (Hillel 1980), as summarized in U.S. EPA (1990a). A range of 0.83 to 1.84 was originally cited in Hoffman and Baes (1979). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g/cm³, based on a mean value for loam soil that was obtained from Carsel, Parrish, Jones, Hansen, and Lamb (1988). The value of 1.5 g/cm³ also represents the midpoint of the "relatively narrow range" for *BD* of 1.2 to 1.7 g/cm³ (U.S. EPA 1993a). The following uncertainty is associated with this variable: The recommended *BD* value may not accurately represent site-specific soil conditions; and may under- or overestimate site-specific soil conditions to an unknown degree.

Variable	Description	Units	Value
F_v	Fraction of COPC air concentration in vapor phase	unitless	**0 to 1** This variable is COPC-specific. Discussion of this variable and COPC-specific values is presented in Appendix A-3. This range is based on values presented in Appendix A-3. Values are also presented in U.S. EPA (1994b) and NC DEHNR (1997). F_v was calculated using an equation presented in Junge (1977) for all organic COPCs, including PCDDs and PCDFs. U.S. EPA (1994c) states that $F_v = 0$ for all metals (except mercury). The following uncertainties are associated with this variable: (1) It is based on the assumption of a default S_T value or background plus local sources, rather than an S_T value for urban sources. If a specific site is located in an urban area, the use of the latter S_T value may be more appropriate. Specifically, the S_T value for urban sources is about one order of magnitude greater than that for background plus local sources, and it would result in a lower calculated F_v value; however, the F_v value is likely to be only a few percent lower. (2) According to Bidleman (1988), the equation used to calculate F_v assumes that the variable *c* (Junge constant) is constant for all chemicals; however, the value of *c* depends on the chemical (sorbate) molecular weight, the surface concentration for monolayer coverage, and the difference between the heat of desorption from the particle surface and the heat of vaporization of the liquid-phase sorbate. To the extent that site- or COPC-specific conditions may cause the value of *c* to vary, uncertainty is introduced if a constant value of *c* is used to calculate F_v.
0.31536	Units conversion factor	m-g-s/cm-µg-yr	
Vdv	Dry deposition velocity	cm/s	**3** U.S. EPA (1994c) recommended the use of 3 cm/s for the dry deposition velocity, based on median dry deposition velocity for HNO_3 from an unspecified U.S. EPA database of dry deposition velocities for HNO_3, ozone, and SO_2. HNO_3 was considered the most similar to the COPCs recommended for consideration in the HHRAP. The value should be applicable to any organic COPC with a low Henry's Law Constant. The following uncertainty is associated with this variable: HNO_3 may not adequately represent specific COPCs; therefore, the use of a single value may under- or overestimate estimated soil concentration.
Cyv	Unitized yearly average air concentration from vapor phase	µg-s/g-m^3	**Varies** This variable is COPC- and site-specific, and is determined by air modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.

TABLE B-3-1

SOIL CONCENTRATION DUE TO DEPOSITION
(CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Description	Units	Value
Dywv	Unitized yearly average wet deposition from vapor phase	s/m^2-yr	**Varies** This variable is COPC- and site-specific, and is determined by air modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.
Dydp	Unitized yearly average dry deposition from particle phase	s/m^2-yr	**Varies** This variable is COPC- and site-specific, and is determined by air modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.
Dywp	Unitized yearly average wet deposition from particle phase	s/m^2-yr	**Varies** This variable is COPC- and site-specific, and is determined by air modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.

REFERENCES AND DISCUSSION

Bidleman, T.F. 1988. "Atmospheric Processes." *Environmental Science and Technology.* Volume 22. Number 4. Pages 361-367.

This reference is for the statement that the equation used to calculate the fraction of air concentration in vapor phase (F_v) assumes that the variable c (the Junge constant) is constant for all chemicals. However, this document notes that the value of c depends on the chemical (sorbate) molecular weight, the surface concentration for monolayer coverage, and the difference between the heat of desorption from the particle surface and the heat of vaporization of the liquid phase sorbate. The following equation, presented in this document, is cited by U.S. EPA (1994b) and NC DEHNR (1997) for calculating the variable F_v:

$$F_v = 1 - \frac{c \cdot S_T}{P^{\circ}_L + c \cdot S_T}$$

where

F_v	=	Fraction of chemical air concentration in vapor phase (unitless)
c	=	Junge constant = 1.7 x 10^{-04} (atm-cm)
S_T	=	Whitby's average surface area of particulates = 3.5 x 10^{-06} (cm²/cm³ air) (corresponds to background plus local sources)
P°_L	=	Liquid phase vapor pressure of chemical (atm) (see Appendix A-3)

If the chemical is a solid at ambient temperatures, the solid-phase vapor pressure is converted to a liquid-phase vapor pressure as follows:

$$\ln \frac{P^{\circ}_L}{P^{\circ}_S} = \frac{\Delta S_f}{R} \cdot \frac{(T_m - T_a)}{T_a}$$

where

P°_S	=	Solid-phase vapor pressure of chemical (atm) (see Appendix A-3)
$\frac{\Delta S_f}{R}$	=	Entropy of fusion over the universal gas constant = 6.79 (unitless)
T_m	=	Melting point of chemical (K) (see Appendix A-3)
T_a	=	Ambient air temperature = 284 K (11°C)

Carsel, R.F., R.S. Parrish, R.L. Jones, J.L. Hansen, and R.L. Lamb. 1988. "Characterizing the Uncertainty of Pesticide Leaching in Agricultural Soils." *Journal of Contaminant Hydrology.* Vol. 2. Pages 11-24.

This reference is cited by U.S. EPA (1994b) as the source for a mean soil bulk density value of 1.5 (g soil/cm^3 soil) for loam soil.

Hillel, D. 1980. *Fundamentals of Soil Physics.* Academic Press, Inc. New York.

This document is cited by U.S. EPA (1990a) for the statement that soil bulk density, *BD*, is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil.

Hoffman, F.O., and C.F. Baes, 1979. *A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides.* ORNL/NOREG/TM-882.

This document presents a soil bulk density range, *BD*, of 0.83 to 1.84.

Junge, C.E. 1977. *Fate of Pollutants in Air and Water Environments, Part I.* Suffet, I.H., Ed. Wiley. New York. Pages 7-26.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This is one of the source documents for the equation in Table B-1-1. This document also recommends the use of (1) a deposition term, *Ds*, and (2) COPC-specific F_v (fraction of COPC air concentration in vapor phase) values.

Research Triangle Institute (RTI). 1992. *Preliminary Soil Action Level for Superfund Sites.* Draft Interim Report. Prepared for U.S. EPA Hazardous Site Control Division, Remedial Operations Guidance Branch. Arlington, Virginia. EPA Contract 68-W1-0021. Work Assignment No. B-03, Work Assignment Manager Loren Henning. December.

This document is a reference source for COPC-specific F_v (fraction of COPC air concentration in vapor phase) values.

U.S. EPA. 1990a. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600-90-003. January.

This document is a reference source for the equation in Table B-3-1, and it recommends that (1) the time period over which deposition occurs (time period for combustion), *tD*, be represented by periods of 30, 60 and 100 years, and (2) undocumented values for soil mixing zone depth, Z_s, for tilled and untilled soil.

U.S. EPA. 1990b. *Exposure Factors Handbook.* March.

This document is a reference source for values for length of exposure duration, T_2.

U.S. EPA. 1992. *Estimating Exposure to Dioxin-Like Compounds.* Draft Report. Office of Research and Development. Washington, D.C. EPA/600/6-88/005b.

This document is cited by U.S. EPA (1993a) as the source of values for soil mixing zone depth, Z_s, for tilled and untilled soils.

U.S. EPA. 1993a. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, D.C. November.

This document is a reference for recommended values for soil mixing zone depth, Z_s, for tilled and untilled soils; it cites U.S. EPA (1992) as the source of these values. It also recommends a "relatively narrow" range for soil bulk density, *BD*, of 1.2 to 1.7 (g soil/cm^3 soil).

U.S. EPA. 1993b. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Working Group Recommendations. Office of Solid Waste. Office of Research and Development. Washington, D.C. September 24.

This document is a reference for the equation in Table B-3-1. It recommends using a deposition term, *Ds*, and COPC-specific F_v values (fraction of COPC air concentration in vapor phase) in the *Cs* equation.

U.S. EPA 1994a. *Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. April 15.

This document is a reference for the equation in Table B-3-1; it recommends that the following be used in the *Cs* equation: (1) a deposition term, *Ds*, and (2) a default soil bulk density value of 1.5 g/cm^3, based on a mean value for loam soil from Carsel, Parrish, Jones, Hansen, and Lamb (1988).

U.S. EPA. 1994b. *Estimating Exposure to Dioxin-Like Compounds. Volume III: Site-Specific Assessment Procedures.* External Review Draft. Office of Research and Development. Washington, D.C. EPA/600/6-88/005Cc. June.

This document recommends values for length of exposure duration, T_2, for the subsistence farmer.

U.S. EPA. 1994c. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

The value for dry deposition velocity is based on median dry deposition velocity for HNO_3 from a U.S. EPA database of dry deposition velocities for HNO3 ozone, and SO_2. HNO_3 was considered the most similar to the constituents covered and the value should be applicable to any organic compound having a low Henry's Law Constant. The reference document for this recommendation was not cited. This document recommends the following:

- Values for the length of exposure duration, T_2
- Value of 0 for the time period of the beginning of combustion, T_1
- F_v values (fraction of COPC air concentration in vapor phase) that range from 0.27 to 1 for organic COPCs
- *Vdv* value (dry deposition velocity) of 3 cm/s (however, no reference is provided for this recommendation)
- Default soil bulk density value of 1.5 (g soil/cm^3 soil), based on a mean for loam soil from Carsel, Parrish, Jones, Hansen, and Lamb (1988)
- *Vdv* value of 3 cm/s, based on median dry deposition velocity for HNO_3 from an unspecified U.S. EPA database of dry deposition velocities for HNO_3, ozone, and SO_2. HNO_3 was considered the most similar to the COPCs recommended for consideration in the HHRAP.

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

COPC SOIL LOSS CONSTANT
(CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Description

This equation calculates the COPC soil loss constant, which accounts for the loss of COPCs from soil by several mechanisms. Uncertainties associated with this equation include the following:

(1) COPC-specific values for *ksg* are empirically determined from field studies; no information is available regarding the application of these values to the site-specific conditions associated with affected facilities.

(2) The source of the equations in Tables B-3-3 through B-3-6 has not been identified.

Equation

$$ks = ksg + kse + ksr + ksl + ksv$$

Variable	Description	Units	Value
ks	COPC soil loss constant due to all processes	yr^{-1}	
ksg	COPC soil loss constant due to biotic and abiotic degradation	yr^{-1}	**Varies** This variable is COPC-specific and should be determined from the COPC tables in Appendix A-3. "Degradation rate" values are also presented in NC DEHNR (1997); however, no reference or source is provided for the values. U.S. EPA (1994a) and U.S. EPA (1994b) state that *ksg* values are COPC-specific; however, all *ksg* values are presented as zero (U.S. EPA 1994a) or as "NA" (U.S. EPA 1994b); the basis of these assumptions is not addressed. The following uncertainty is associated with this variable: COPC-specific values for *ksg* are empirically determined from field studies; no information is available regarding the application of these values to the site-specific conditions associated with affected facilities.

TABLE B-3-2

COPC SOIL LOSS CONSTANT
(CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Description	Units	Value
kse	COPC loss constant due to soil erosion	yr^{-1}	**0** This variable is COPC- and site-specific, and is further discussed in Table B-3-3. Consistent with U.S. EPA (1994a), U.S. EPA (1994b) and NC DEHNR (1997), U.S. EPA OSW recommends that the default value assumed for *kse* is zero because of contaminated soil eroding onto the site and away from the site. Uncertainties associated with this variable include the following: (1) The source of the equation in Table B-3-3 has not been identified. (2) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting a greater mixing depth. This uncertainty may overestimate *kse*. (3) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *kse*.
ksr	COPC loss constant due to surface runoff	yr^{-1}	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-3-4. No reference document is cited for this equation; the use of this equation is consistent with U.S. EPA (1994b) and NC DEHNR (1997). U.S. EPA (1994a) states that all *ksr* values are zero but does not explain the basis of this assumption. Uncertainties associated with this variable (calculated by using the equation in Table B-3-4) include the following: (1) The source of the equation in Table B-3-4 has not been identified. (2) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksr*. (3) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksr*.
ksl	COPC loss constant due to leaching	yr^{-1}	**Varies** This variable is COPC- and site-specific, and is calculated by the using equation in Table B-3-5. The use of this equation is consistent with U.S. EPA (1993) and U.S. EPA (1994b), and NC DEHNR (1997). U.S. EPA (1994a) states that all *ksl* values are zero but does not explain the basis of this assumption. Uncertainties associated with this variable (calculated by using the equation in Table B-3-5) include the following: (1) The source of the equation in Table B-3-5 has not been identified. (2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksl*.

TABLE B-3-2

COPC SOIL LOSS CONSTANT
(CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Description	Units	Value
ksv	COPC loss constant due to volatilization	yr^{-1}	**0** This variable is COPC- and site-specific, and is further discussed in Table B-3-6. Consistent with U.S. EPA guidance (1994a) and based on the need for additional research to be conducted to determine the magnitude of the uncertainty introduced for modeling volatile COPCs from soil, U.S. EPA OSW recommends that, until identification and validation of more applicable models, the constant for the loss of soil resulting from volatilization (*ksv*) should be set equal to zero. Uncertainties associated with this variable include the following: (1) The source of the equation in Table B-3-6 has not been identified. (2) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting a greater mixing depth. This uncertainty may overestimate *ksv*. (3) Deposition to hard surfaces may result in dust residues that have negligible dilution, (as a result of potential mixing with in-situ materials) in comparison to that of other residues. This uncertainty may underestimate *ksv*.

REFERENCES AND DISCUSSION

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is one of the reference documents for the equations in Tables B-3-4, B-3-5, and B-3-6. This document is also cited as (1) the source for a range of COPC-specific degradation rates (*ksg*), and (2) one of the sources that recommend using the assumption that the loss resulting from erosion (*kse*) is zero because of contaminated soil eroding onto the site and away from the site.

U.S. EPA. 1993c. *Review Draft Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Office of Health and Environmental Assessment. Office of Research and Development. EPA-600-AP-93-003. November 10.

This document is one of the reference documents for the equations in Tables B-3-3 and B-3-5.

U.S. EPA. 1994a. *Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* April 15.

This document is cited as a source for the assumptions that losses resulting from erosion (*kse*), surface runoff (*ksr*), degradation (*ksg*), leaching (*ksl*), and volatilization (*ksv*) are all zero.

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document is one of the reference documents for the equations in Tables B-3-4, B-3-5, and B-3-6. This document is also cited as one of the sources that recommend using the assumption that the loss resulting from erosion (*kse*) is zero and the loss resulting from degradation (*ksg*) is "NA" or zero for all compounds.

TABLE B-3-3

COPC LOSS CONSTANT DUE TO SOIL EROSION (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Description

This equation calculates the constant for COPC loss resulting from erosion of soil. Consistent with U.S. EPA (1994), U.S. EPA (1994b), and NC DEHNR (1997), U.S. EPA OSW recommends that the default value assumed for *kse* is zero because of contaminated soil eroding onto the site and away from the site. In site-specific cases where the permitting authority considers it appropriate to calculate a *kse*, the following equation presented in this table should be considered along with associated uncertainties. Additional discussion on the determination of *kse* can be obtained from review of the methodologies described in U.S. EPA NCEA document, *Methodology for Assessing Health Risks Associated with Multiple Exposure Pathways to Combustor Emissions* (In Press). Uncertainties associated with this equation include:

(1) For soluble COPCs, leaching might lead to movement below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *kse*.

(2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *kse*.

Equation

$$kse = \frac{0.1 \cdot X_e \cdot SD \cdot ER}{BD \cdot Z_s} \cdot \left(\frac{Kd_s \cdot BD}{\theta_{sw} + (Kd_s \cdot BD)} \right)$$

Variable	Description	Units	Value
kse	COPC loss constant due to soil erosion	yr^{-1}	**0** Consistent with U.S. EPA (1994), U.S. EPA (1994b), and NC DEHNR (1997), U.S. EPA OSW recommends that the default value assumed for *kse* is zero because of contaminated soil eroding onto the site and away from the site. uncertainty may overestimate *kse*.
X_e	Unit soil loss	kg/m^2-yr	**Varies** This variable is site-specific and is calculated by using the equation in Table B-4-13. The following uncertainty is associated with this variable: All of the equation variables are site-specific. Use of default values rather than site-specific values for any or all of these variables will result in unit soil loss (X_e) estimates that are under- or overestimated to some degree. Based on default values, X_e estimates can vary over a range of less than two orders of magnitude.

TABLE B-3-3

COPC LOSS CONSTANT DUE TO SOIL EROSION (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Description	Units	Value
SD	Sediment delivery ratio	unitless	**Varies** This value is site-specific and is calculated by using the equation in Table B-4-14. Uncertainties associated with this variable include the following: (1) The recommended default values for the empirical intercept coefficient, *a*, are average values that are based on studies of sediment yields from various watersheds. Therefore, those default values may not accurately represent site-specific watershed conditions. As a result, use of these default values may under- or overestimate *SD*. (2) The recommended default value for the empirical slope coefficient, *b*, is based on a review of sediment yields from various watersheds. This single default value may not accurately represent site-specific watershed conditions. As a result, use of this default value may under- or overestimate *SD*.
ER	Soil enrichment ratio	unitless	**Inorganics: 1** **Organics: 3** COPC enrichment occurs because (1) lighter soil particles erode more than heavier soil particles, and (2) concentration of organic COPCs—which is a function of organic carbon content of sorbing media—is expected to be higher in eroded material than in *in-situ* soil (U.S. EPA 1993). In the absence of site-specific data, U.S. EPA OSW recommends a default value of 3 for organic COPCs and 1 for inorganic COPCs. This is consistent with other U.S. EPA guidance (1993), which recommends a range of 1 to 5 and a value of 3 as a "reasonable first estimate." This range has been used for organic matter, phosphorus, and other soil-bound COPCs (U.S. EPA 1993); however, no sources or references were provided for this range. *ER* is generally higher in sandy soils than in silty or loamy soils (U.S. EPA 1993). The following uncertainty is associated with this variable: The default *ER* value may not accurately reflect site-specific conditions; therefore, *kse* may be over- or underestimated to an unknown extent. The extent of any uncertainties will be reduced by using county-specific *ER* values.
BD	Soil bulk density	g soil/cm^3 soil	**1.5** This variable is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil (Hillel 1980), as summarized in U.S. EPA (1990). A range of 0.83 to 1.84 was originally cited in Hoffman and Baes (1979). U.S. EPA (1994b) recommended a default BD value of 1.5 (g soil/cm^3 soil), based on a mean value for loam soil that was taken from Carsel, Parrish, Jones, Hansen, and Lamb (1988). The value of 1.5 (g soil/cm^3 soil) also represents the midpoint of the "relatively narrow range" for *BD* of 1.2 to 1.7 (g soil/cm^3 soil) (U.S. EPA 1993). The following uncertainty is associated with this variable: The recommended soil bulk density value may not accurately represent site-specific soil conditions.

TABLE B-3-3

COPC LOSS CONSTANT DUE TO SOIL EROSION (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Description	Units	Value
Z_s	Soil mixing zone depth	cm	**1 to 20** U.S. EPA currently recommends the following values for this variable: Soil / Depth (cm) / Reference Untilled / 1 / U.S. EPA (1990a) and U.S. EPA (1993a) Tilled / 20 / U.S. EPA (1990a) and U.S. EPA (1993a) U.S. EPA (1990) does not provide a reference for these values. U.S. EPA (1993) cites U.S. EPA (1994a). Uncertainties associated with this variable include the following: (1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *kse*. (2) Deposition to hard surfaces may result in dust residues that have negligible dilution in comparison to that of other residues. This uncertainty may underestimate *kse*.
Kd_s	Soil-water partition coefficient	mL water/g soil (or cm^3 water/g soil)	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Uncertainties associated with this parameter will be limited if Kd_s values are calculated as described in Appendix A-3.
θ_{sw}	Soil volumetric water content	mL water/cm^3 soil	**0.2** This variable is site-specific, and depends on the available water and on soil structure; θ_s can be estimated as the midpoint between a soil's field capacity and wilting point, if a representative watershed soil can be identified. However, U.S. EPA recommends the use of 0.2 mL/cm^3 as a default value. This value is the midpoint of the range 0.1 (very sandy soils) to 0.3 (heavy loam/clay soils) recommended by U.S. EPA (1993) (no source or reference is provided for this range) and is consistent with U.S. EPA (1994b). The following uncertainty is associated with this variable: The default θ_{sw} value may not accurately reflect site-specific or local conditions; therefore, *kse* may be under- or overestimated to a small extent, based on the limited range of values.

REFERENCES AND DISCUSSION

Carsel, R.F., R.S. Parish, R.L. Jones, J.L. Hansen, and R.L. Lamb. 1988. "Characterizing the Uncertainty of Pesticide Leaching in Agricultural Soils." *Journal of Contaminant Hydrology*. Vol. 2. Pages 11-24.

This document is cited by U.S. EPA (1994b) as the source for a mean soil bulk density, *BD*, value of 1.5 (g soil/cm^3 soil) for loam soil.

Hillel, D. 1980. *Fundamentals of Soil Physics*. Academic Press, Inc. New York.

This document is cited by U.S. EPA (1990) for the statement that soil bulk density, *BD*, is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil.

Hoffman, F.O., and C.F. Baes. 1979. *A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides*. ORNL/NUREG/TM-882.

This document presents a soil bulk density, *BD*, range of 0.83 to 1.84.

U.S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions*. Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600-90-003. January.

This document presents a range of values for soil mixing zone depth, Z_s, for tilled and untilled soil. The basis or source of these values is not identified.

U.S. EPA. 1993. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions*. External Review Draft. Office of Research and Development. Washington, D.C. November 1993.

This document is the source of a range of COPC enrichment ratio, *ER*, values. The recommended range, 1 to 5, has been used for organic matter, phosphorous, and other soil-bound COPCs. This document recommends a value of 3 as a "reasonable first estimate," and states that COPC enrichment occurs because lighter soil particles erode more than heavier soil particles. Lighter soil particles have higher ratios of surface area to volume and are higher in organic matter content. Therefore, concentration of organic COPCs, which is a function of the organic carbon content of sorbing media, is expected to be higher in eroded material than in *in situ* soil.

This document is also a source of the following:

- A "relatively narrow range" for soil bulk density, *BD*, of 1.2 to 1.7 (g soil/cm^3 soil)
- COPC-specific (inorganic COPCs only) Kd_s values used to develop a proposed range (2 to 280,000 [mL water/g soil]) of Kd_s values
- A range of soil volumetric water content (θ_{sw}) values of 0.1 (mL water/cm^3 soil) (very sandy soils) to 0.3 (mL water/cm^3 soil) (heavy loam/clay soils) (however, no source or reference is provided for this range)
- A range of values for soil mixing zone depth, Z_s, for tilled and untilled soil

U.S. EPA. 1994. *Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities*. April 15.

U.S. EPA. 1994a. *Estimating Exposure to Dioxin-Like Compounds. Volume III: Site-specific Assessment Procedures.* External Review Draft. Office of Research and Development. Washington, D.C. EPA/600/6-88/005Cc. June.

This document is the source of values for soil mixing zone depth, Z_s, for tilled and untilled soil, as cited in U.S. EPA (1993). U.S. EPA is reviewing the document to verify the original source of, or reference for, the recommended mixing zone values.

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document recommends (1) a default soil bulk density value of 1.5 (g soil/cm^3 soil), based on a mean value for loam soil that is taken from Carsel, Parrish, Jones, Hansen, and Lamb (1988), and (2) a default soil volumetric water content, θ_{sw}, value of 0.2 (mL water/cm^3 soil), based on U.S. EPA (1993).

TABLE B-3-4

COPC LOSS CONSTANT DUE TO RUNOFF
(CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Description

This equation calculates the COPC loss constant due to runoff of soil. Uncertainties associated with this equation include the following:

(1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksr*.
(2) Deposition to hard surfaces may result in dust residues that have negligible dilution in comparison to that of other residues. This uncertainty may underestimate *ksr*.

Equation

$$ksr = \frac{RO}{\theta_{sw} \cdot Z_s} \cdot \left(\frac{1}{1 + \left(Kd_s \cdot BD / \theta_{sw}\right)} \right)$$

Variable	Description	Units	Value
ksr	COPC loss constant due to runoff	yr^{-1}	
RO	Average annual surface runoff from pervious areas	cm/yr	**Varies** This variable is site-specific. According to U.S. EPA (1993), U.S. EPA (1994b), and NC DEHNR (1997), average annual surface runoff, *RO*, can be estimated by using the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973). According to NC DEHNR (1997), estimates can also be made by using more detailed, site-specific procedures for estimating the amount of surface runoff, such as those based on the U.S. Soil Conservation Service curve number equation (CNE). U.S. EPA (1985) is cited as an example of such a procedure. The following uncertainty is associated with this variable: To the extent that site-specific or local average annual surface runoff information is not available, default or estimated values may not accurately represent site-specific or local conditions. As a result, *ksl* may be under- or overestimated to an unknown degree.

TABLE B-3-4

COPC LOSS CONSTANT DUE TO RUNOFF (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Description	Units	Value
θ_{sw}	Soil volumetric water content	mL water/cm^3 soil	**0.2** This variable is depends on the available water and soil structure; if a representative watershed soil can be identified, θ_{sw} can be estimated as the midpoint between a soil's field capacity and wilting point. U.S. EPA OSW recommends the use of 0.2 (mL water/cm^3 soil) as a default value. This value is the midpoint of the range 0.1 (very sandy soils) to 0.3 (heavy loam/clay soils), which is recommended by U.S. EPA (1993) (no source or reference is provided for this range), and is consistent with U.S. EPA (1994b) and NC DEHNR (1997). The following uncertainty is associated with this variable: The default θ_{sw} value may not accurately reflect site-specific or local conditions; therefore, *kse* may be under- or overestimated to a small extent, based on the limited range of values.
Z_s	Soil mixing zone depth	cm	**1 to 20** U.S. EPA OSW recommends the following values for this variable: Soil / Depth (cm) / Reference Untilled / 1 / U.S. EPA (1990a) and U.S. EPA (1993a) Tilled / 20 / U.S. EPA (1990a) and U.S. EPA (1993a) U.S. EPA (1990) does not provide a reference for these values. U.S. EPA (1993) cites U.S. EPA (1994a). Uncertainties associated with this variable include the following: (1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksr*. (2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksr*.
Kd_s	Soil-water partition coefficient	mL water/g soil (or cm^3 water/g soil)	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Uncertainties associated with this parameter will be limited if Kd_s values are calculated as described in Appendix A-3.

TABLE B-3-4

COPC LOSS CONSTANT DUE TO RUNOFF (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Description	Units	Value
BD	Soil bulk density	g soil/cm^3 soil	**1.5** This variable is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil (Hillel 1980), as summarized in U.S. EPA (1990). The proposed range was originally cited in Hoffman and Baes (1979). U.S. EPA (1994b) recommended a default soil bulk density value of 1.5 g/cm^3, based on a mean value for loam soil that is taken from Carsel, Parrish, Jones, Hansen, and Lamb (1988). The value of 1.5 g/cm^3 also represents the midpoint of the "relatively narrow range" for *BD* of 1.2 to 1.7 g/cm^3 (U.S. EPA 1993). The following uncertainty is associated with this variable: The recommended soil bulk density value may not accurately represent site-specific soil conditions.

REFERENCES AND DISCUSSION

Carsel, R.F., R.S. Parrish, R.L. Jones, J.L. Hansen, and R.L. Lamb. 1988. "Characterizing the Uncertainty of Pesticide Leaching in Agricultural Soils." *Journal of Contaminant Hydrology*. Vol. 2. Pages 11-24.

This document is cited by U.S. EPA (1994b) as the source of a mean soil bulk density, *BD*, value of 1.5 (g soil/cm^3 soil) for loam soil.

Geraghty, J.J., D.W. Miller, F. Van der Leeden, and F.L. Troise. 1973. *Water Atlas of the United States*. Water Information Center, Port Washington, New York.

This document is cited by U.S. EPA (1993), U.S. EPA (1994), and NC DEHNR (1997) as a reference to calculate average annual runoff, *RO*. This reference provides maps with isolines of annual average surface water runoff, which is defined as all flow contributions to surface water bodies, including direct runoff, shallow interflow, and ground water recharge. Because these values are total contributions and not only surface runoff, U.S. EPA (1994) recommends that the volumes be reduced by 50 percent in order to estimate surface runoff.

Hillel, D. 1980. Fundamentals of Soil Physics. Academic Press, Inc. New York.

This document is cited by U.S. EPA (1990) for the statement that soil bulk density, *BD*, is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil.

Hoffman, F.O., and C.F. Baes. 1979. *A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides*. ORNL/NUREG/TM-882.

This document presents a soil bulk density, *BD*, range of 0.83 to 1.84.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units*. January.

This document is one of the source documents that cites the use of Table B-3-4; however, this document is not the original source of this equation (this source is unknown). This document also recommends the following:

- Estimation of annual current runoff, *RO* (cm/yr), by using the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973) or site-specific procedures, such as using the U.S. Soil Conservation Service curve number equation (CNE); U.S. EPA (1985) is cited as an example of such a procedure.
- Default value of 0.2 (mL water/cm^3 soil) for soil volumetric water content (θ_{sw})

U.S. EPA. 1985. *Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water—Part I (Revised. 1985)*. Environmental Research Laboratory. Athens, Georgia. EPA/600/6-85/002a. September.

This document is cited by NC DEHNR (1997) as an example of the use of the U.S. Soil Conservation Service CNE to estimate site-specific surface runoff.

U.S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions*. Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600-90-003. January.

This document presents a range of values for soil mixing zone depth, Z_s, for tilled and untilled soil; the basis for, or sources of, these values is not identified.

U.S. EPA. 1993. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, D.C. November.

This document recommends the following:

- A "relatively narrow range" for soil bulk density, *BD*, of 1.2 to 1.7 (g soil./cm^3 soil)
- A range of soil volumetric water content, θ_{sw}, values of 0.1 (very sandy soils) to 0.3 (heavy loam/clay soils) (the original source of, or reference for, these values is not identified)
- A range of values for soil mixing depth, Z_s, for tilled and untilled soil (the original source of, or reference for, these values is not identified)
- A range (2 to 280,000 [mL water/g soil]) of Kd_s values for inorganic COPCs
- Use of the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973) to calculate average annual runoff, *RO*.

U.S. EPA. 1994a. *Estimating Exposure to Dioxin-Like Compounds. Volume III: Site-specific Assessment Procedures.* External Review Draft. Office of Research and Development. Washington, D.C. EPA/600/6-88/005Cc. June.

This document is the source of values for soil mixing zone depth, Z_s, for tilled and untilled soil, as cited in U.S. EPA (1993). U.S. EPA is reviewing the document to verify the original source of, or reference for, the recommended mixing zone values.

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes.* Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities. Offices of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document recommends the following:

- Estimation of average annual runoff, *RO*, by using the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973)
- Default soil bulk density, *BD*, value of 1.5 (g soil/cm^3 soil), based on the mean for loam soil that is taken from Carsel, Parrish, Jones, Hansen, and Lamb (1988)
- Default soil volumetric water content, θ_{sw}, value of (0.2 mL water/cm^3 soil), based on U.S. EPA (1993)

TABLE B-3-5

COPC LOSS CONSTANT DUE TO LEACHING (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Description

This equation calculates the COPC loss constant due to leaching of soil. Uncertainties associated with this equation include the following:

(1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksl*.
(2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *insitu* materials) in comparison to that of other residues. This uncertainty may underestimate *ksl*.
(3) The original source of this equation has not been identified. U.S. EPA (1993) presents the equation as shown here. U.S. EPA (1994b) and NC DEHNR (1997) replaced the numerator as shown with "*q*", defined as average annual recharge (cm/yr).

Equation

$$ksl = \frac{P + I - RO - E_v}{\theta_{sw} \cdot Z_s \cdot \left[1.0 + \left(BD \cdot Kd_s / \theta_{sw}\right)\right]}$$

Variable	Description	Units	Value
ksl	Constant for COPC loss due to soil leaching	yr^{-1}	
P	Average annual precipitation	cm/yr	**18.06 to 164.19** This variable is site-specific. This range is based on information presented in U.S. EPA (1990), representing data for 69 selected cities (U.S. Bureau of Census 1987; Baes, Sharp, Sjoreen and Shor 1984). The 69 selected cities are not identified; however, they appear to be located throughout the continental United States. U.S. EPA OSW recommends that site-specific data be used. The following uncertainty is associated with this variable: (1) To the extent that a site is not located near an established meteorological data station, and site-specific data are not available, default average annual precipitation data may not accurately reflect site-specific conditions. As a result, *ksl* may be under- or overestimated. However, average annual precipitation data are reasonably available; therefore, uncertainty introduced by this variable is expected to be minimal.

TABLE B-3-5

COPC LOSS CONSTANT DUE TO LEACHING (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Description	Units	Value
I	Average annual irrigation	cm/yr	**0 to 100** This variable is site-specific. This range is based on information presented in U.S. EPA (1990), representing data for 69 selected cities (Baes, Sharp, Sjoreen, and Shor 1984). The 69 selected cities are not identified; however, they appear to be located throughout the continental United States. The following uncertainty is associated with this variable: To the extent that site-specific or local average annual irrigation information is not available, default values (generally based on the closest comparable location) may not accurately reflect site-specific conditions. As a result, *ksl* may be under- or overestimated to an unknown degree.
RO	Average annual surface runoff from pervious areas	cm/yr	**Varies** This variable is site-specific. According to U.S. EPA (1993), U.S. EPA (1994b), and NC DEHNR (1997), average annual surface runoff, *RO*, can be estimated by using the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973). According to NC DEHNR (1997), this estimate can also be made by using more detailed, site-specific procedures, such as those based on the U.S. Soil Conservation Service CNE. U.S. EPA (1985) is cited as an example of such a procedure. The following uncertainty is associated with this variable: To the extent that site-specific or local average annual surface runoff information is not available, default or estimated values may not accurately represent site-specific or local conditions. As a result, *ksl* may be under- or overestimated to an unknown degree.
E_v	Average annual evapotranspiration	cm/yr	**35 to 100** This variable is site-specific. This range is based on information presented in U. S. EPA (1990), representing data from 69 selected cities. The 69 selected cities are not identified; however, they appear to be located throughout the continental United States. The following uncertainty is associated with this variable: To the extent that site-specific or local average annual evapotranspiration information is not available, default values may not accurately reflect site-specific conditions. As a result, *ksl* may be under- or overestimated to an unknown degree.

TABLE B-3-5

COPC LOSS CONSTANT DUE TO LEACHING (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Description	Units	Value
θ_{sw}	Soil volumetric water content	mL water/cm^3 soil	**0.2** This variable is site-specific, and depends on the available water and on soil structure; if a representative watershed soil can be identified, θ_{sw} can be estimated as the midpoint between a soil's field capacity and wilting point. U.S. EPA OSW recommends the use of 0.2 (mL soil/cm^3 water) as a default value. This value is the midpoint of the range of 0.1 (very sandy soils) to 0.3 (heavy loam/clay soils) recommended by U.S. EPA (1993) (no source or reference is provided for this range) and is consistent with U.S. EPA (1994b) and NC DEHNR (1997). The following uncertainty is associated with this variable: The default θ_{sw} value may not accurately reflect site-specific or local conditions; therefore, *ksl* may be under- or overestimated to a small extent, based on the limited range of values.
Z_s	Soil mixing zone depth	cm	**1 to 20** U.S. EPA OSW recommends the following values for this variable: Soil — Depth (cm) — Reference Untilled — 1 — U.S. EPA (1990a) and U.S. EPA (1993a) Tilled — 20 — U.S. EPA (1990a) and U.S. EPA (1993a) U.S. EPA (1990) does not provide a reference for these values. U.S. EPA (1993a) cites U.S. EPA (1994a). Uncertainties associated with this variable include the following: (1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksr*. (2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in-situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksl*.
BD	Soil bulk density	g soil/cm^3 soil	**1.5** This variable is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil (Hillel 1980), as summarized in U.S. EPA (1990). A range of 0.83 to 1.84 was originally cited in Hoffman and Baes (1979). U.S. EPA (1994b) recommended a default soil bulk density value of 1.5 (g soil/cm^3 soil), based on a mean value for loam soil from Carsel, Parrish, Jones, Hansen, and Lamb (1988). The value of 1.5 (g soil/cm^3 soil) also represents the midpoint of the "relatively narrow range" for *BD* of 1.2 to 1.7 (g soil/cm^3 soil) (U.S. EPA 1993). The following uncertainty is associated with this variable: The recommended soil bulk density value may not accurately represent site-specific soil conditions.

TABLE B-3-5

COPC LOSS CONSTANT DUE TO LEACHING (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Description	Units	Value
Kd_s	Soil-water partition coefficient	cm^3 water/g soil	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Uncertainties associated with this parameter will be limited if Kd_s values are calculated as described in Appendix A-3.

REFERENCES AND DISCUSSION

Baes, C.F., R.D. Sharp, A.L. Sjoreen and R.W. Shor. 1984. "A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture." Prepared for the U.S. Department of Energy under Contract No. DEAC05-840R21400.

For the continental United States, as cited in U.S. EPA (1990), this document is the source of a series of maps showing: (1) average annual precipitation (*P*), (2) average annual irrigation (*I*), and (3) average annual evapotranspiration isolines.

Carsel, R.F., R.S. Parrish, R.L. Jones, J.L. Hansen, and R.L. Lamb. 1988. "Characterizing the Uncertainty of Pesticide Leaching in Agricultural Soils." *Journal of Contaminant Hydrology.* Vol. 2. Pages 11-24.

This document is cited by U.S. EPA (1994b) as the source for a mean soil bulk density value, *BD*, of 1.5 g soil/cm^3 soil for loam soil.

Geraghty, J.J., D.W. Miller, F. Van der Leeden, and F.L. Troise. 1973. *Water Atlas of the United States.* Water Information Center, Port Washington, New York.

This document is cited by U.S. EPA (1993), U.S. EPA (1994b), and NC DEHNR (1997) as a reference for calculating average annual runoff, *RO.* This document provides maps with isolines of annual average surface runoff, which is defined as all flow contributions to surface water bodies, including direct runoff, shallow interflow, and ground water recharge. Because these volumes are total contributions and not only surface runoff, U.S. EPA (1994b) recommends that the volumes be reduced by 50 percent in order to estimate average annual surface runoff.

This document presents a soil bulk density, *BD*, range of 0.83 to 1.84.

Hillel, D. 1980. *Fundamentals of Soil Physics.* Academic Press, Inc. New York, New York.

This document is cited by U.S. EPA (1990) for the statement that soil bulk density, *BD*, is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil.

Hoffman, F.O., and C.F. Baes. 1979. *A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides.* ORNL/NUREG/TM-882.

This document presents a soil bulk density, *BD*, range of 0.83 to 1.84.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is one of the source documents that cites the use of the equation in Table B-1-5. However, the document is not the original source of this equation. This document also recommends the following:

- Estimation of average annual surface runoff, *RO* (cm/yr), by using the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973) or site-specific procedures, such as using the U.S. Soil Conservation Service CNE; U.S. EPA 1985 is cited as an example of such a procedure.
- A default value of 0.2 (mL water/cm^3 soil) for soil volumetric water content, θ_{sw}

U.S. Bureau of the Census. 1987. *Statistical Abstract of the United States:* 1987. 107th edition. Washington, D.C.

This document is a source of average annual precipitation (*P*) information for 69 selected cites, as cited in U.S. EPA (1990); these 69 cities are not identified.

U.S. EPA. 1985. *Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Groundwater.* Part I (Revised 1985). Environmental Research Laboratory. Athens, Georgia. EPA/600/6-85/002a. September.

This document is cited by NC DEHNR (1997) as an example of the use of the U.S. Soil Conservation Service CNE to estimate *RO*.

U.S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600-90-003. January.

This document presents ranges of (1) average annual precipitation, (2) average annual irrigation, and (3) average annual evapotranspiration. This document cites Baes, Sharp, Sjoreen, and Shor (1984) and U.S. Bureau of the Census (1987) as the original sources of this information.

U.S. EPA. 1993. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, D.C. November.

This document is one of the reference sources for the equation in Table B-1-5; this document also recommends the following:

- A range of soil volumetric water content, θ_{sw}, values of 0.1 (very sandy soils) to 0.3 (heavy loam/clay soils); the original source or reference for these values is not identified.
- A range of values for soil mixing depth, Z_s, for tilled and untilled soil; the original source reference for these values is not identified.
- A range (2 to 280,000 [mL water/g soil]) of Kd_s values for inorganic COPCs
- A "relatively narrow range" for soil bulk density, *BD*, of 1.2 to 1.7 (g soil/cm^3 soil)

This document is one of the reference source documents for the equation in Table B-1-5. The original source of this equation is not identified. This document also presents a range of values for soil mixing depth, *Z*, for tilled and untilled soil; the original source of these values is not identified. Finally, this document presents several COPC-specific Kd_s values that were used to establish a range (2 to 280,000 [mL water/g soil]) of Kd_s values.

U.S. EPA. 1994a. *Estimating Exposure to Dioxin-Like Compounds. Volume III: Site-specific Assessment Procedures.* External Review Draft. Office of Research and Development. Washington, D.C. EPA/600/6-88/005Cc. June.

This document is the source of values for soil mixing zone depth, Z_s, for tilled and untilled soil, as cited in U.S. EPA (1993).

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document recommends (1) a default soil volumetric water content, θ_{sw}, value of 0.2 (mL water/cm^3 soil), based on U.S. EPA (1993), and (2) a default soil bulk density, *BD*, value of 1.5 (g soil/cm^3 soil), based on a mean value for loam soil from Carsel, Parrish, Jones, Hansen, and Lamb (1988).

COPC LOSS CONSTANT DUE TO VOLATILIZATION (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Description

This equation calculates the COPC loss constant from soil due to volatilization. Consistent with U.S. EPA guidance (1994) and based on the need for additional research to be conducted to determine the magnitude of the uncertainty introduced for modeling volatile COPCs from soil, U.S. EPA OSW recommends that, until identification and validation of more applicable models, the constant for the loss of soil resulting from volatilization (*ksv*) should be set equal to zero. In cases where high concentrations of volatile organic compounds are expected to be present in the soil and the permitting authority considers calculation of *ksv* to be appropriate, the equation presented in this table should be considered. U.S. EPA OSW also recommends consulting the methodologies described in U.S. EPA NCEA document, *Methodology for Assessing Health Risks Associated with Multiple Exposure Pathways to Combustor Emissions* (In Press).

Uncertainties associated with this equation include the following:

(1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksv*.

(2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksv*.

Equation

$$ksv = \left[\frac{3.1536 \cdot 10^{7} \cdot H}{Z_s \cdot Kd_s \cdot R \cdot T_a \cdot BD}\right] \cdot \left[0.482 \cdot W^{0.78} \cdot \left(\frac{\mu_a}{\rho_a \cdot D_a}\right)^{-0.67} \cdot \left(\sqrt{\frac{4A}{\pi}}\right)^{-0.11}\right]$$

Variable	Definition	Units	Value
ksv	COPC loss constant due to volatilization	yr^{-1}	**0** Consistent with U.S. EPA guidance (1994) and based on the need for additional research to be conducted to determine the magnitude of the uncertainty introduced for modeling volatile COPCs from soil, U.S. EPA OSW recommends that, until identification and validation of more applicable models, the constant for the loss of soil resulting from volatilization (*ksv*) should be set equal to zero.
0.482	Empirical constant	unitless	This is an empirical constant calculated during the development of this equation.
0.78	Empirical constant	unitless	This is an empirical constant calculated during the development of this equation.
-0.67	Empirical constant	unitless	This is an empirical constant calculated during the development of this equation.
-0.11	Empirical constant	unitless	This is an empirical constant calculated during the development of this equation.
$3.1536 \times 10^{+07}$	Units conversion factor	s/yr	

TABLE B-3-6

COPC LOSS CONSTANT DUE TO VOLATILIZATION (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Definition	Units	Value
H	Henry's Law constant	atm-m^3/mol	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific variables are presented in Appendix A-3. The following uncertainty is associated with this variable: Values for this variable, estimated by using the parameters and algorithms in Appendix A-3, may under- or overestimate the actual COPC-specific values. As a result, *ksv* may be under- or overestimated.
Z_s	Soil mixing zone depth	cm	**1 to 20** U.S. EPA OSW recommends the following values for this variable: Soil — Depth (cm) — Reference Untilled — 1 — U.S. EPA (1990a) and U.S. EPA (1993a) Tilled — 20 — U.S. EPA (1990a) and U.S. EPA (1993a) U.S. EPA (1990) does not provide a reference for these values. U.S. EPA (1993a) cites U.S. EPA (1994a). Uncertainties associated with this variable include the following: (1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksr*. (2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksv*.
Kd_s	Soil-water partition coefficient	cm^3 water/g soil	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Uncertainties associated with this parameter will be limited if Kd_s values are calculated as described in Appendix A-3.
R	Universal gas constant	atm-m^3/mol-K	**8.205×10^{-5}** There are no uncertainties associated with this parameter.

TABLE B-3-6

COPC LOSS CONSTANT DUE TO VOLATILIZATION (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Definition	Units	Value
T_a	Ambient air temperature	K	**298** This variable is site-specific. U.S. EPA (1990) recommends an ambient air temperature of 298 K. The following uncertainty is associated with this variable: To the extent that site-specific or local values for the variable are not available, default values may not accurately represent site-specific conditions. The uncertainty associated with the selection of a single value from within the temperature range at a single location is expected to be more significant than the uncertainty associated with choosing a single ambient temperature to represent all localities.
BD	Soil bulk density	g soil/cm^3 soil	**1.5** This variable is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil (Hillel 1980), as summarized in U.S. EPA (1990). A range of 0.83 to 1.84 was originally cited in Hoffman and Baes (1979). U.S. EPA (1994b) recommended a default soil bulk density value of 1.5 g/cm^3, based on a mean value for loam soil from Carsel, Parrish, Jones, Hansen, and Lamb (1988). The value of 1.5 g/cm^3 also represents the midpoint of the "relatively narrow range" for *BD* of 1.2 to 1.7 g/cm^3 (U.S. EPA 1993). The following uncertainty is associated with this variable: The recommended soil bulk density value may not accurately represent site-specific soil conditions.
W	Average annual wind speed	m/s	**3.9** Consistent with U.S. EPA (1990), U.S. EPA OSW recommends a default value of 3.9 m/s. See Chapter 3 for guidance regarding the references and methods used to determine a site-specific value that isconsistent with air dispersion modeling. The following uncertainty is associated with this variable: To the extent that site-specific or local values for this variable are not available, default values may not accurately represent site-specific conditions. The uncertainty associated with the selection of a single value from within the range of windspeeds at a single location may be more significant than the uncertainty associated with choosing a single windspeed to represent all locations.

TABLE B-3-6

COPC LOSS CONSTANT DUE TO VOLATILIZATION (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Definition	Units	Value
μ_a	Viscosity of air	g/cm-s	**1.81 x 10^{-04}** U.S. EPA OSW recommends the use of this value, based on Weast (1980. This value applies at standard conditions (25°C or 298 K and 1 atm or 760 mm Hg). The viscosity of air may vary slightly with temperature.
ρ_a	Density of air	g/cm^3	**0.0012** U.S. EPA recommends the use of this value, based on Weast (1980). This value applies at standard conditions (25°C or 298 K and 1 atm or 760 mm Hg). The density of air will vary with temperature.
D_a	Diffusivity of COPC in air	cm^2/s	**Varies** This value is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: The default D_a values may not accurately represent the behavior of COPCs under site-specific conditions. However, the degree of uncertainty is expected to be minimal.
A	Surface area of contaminated area	m^2	**1.0** See Chapter 5 for guidance regarding the calculation of this value.

REFERENCES AND DISCUSSION

Carsel, R.F., R.S, Parrish, R.L. Jones, J.L. Hansen, and R.L. Lamb. 1988. "Characterizing the Uncertainty of Pesticide Leaching in Agricultural Soils." *Journal of Contaminant Hydrology*. Vol. 2. Pages 11-24.

This document is cited by U.S. EPA (1994b) as the source of a mean soil bulk density value, *BD*, of 1.5 (g soil/cm^3 soil) for loam soil.

Hillel, D. 1980. *Fundamentals of Soil Physics*. Academic Press, Inc. New York, New York.

Hoffman, F.O., and C.F. Baes. 1979. *A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides*. ORNL/NUREG/TM-882.

This document presents a soil bulk density, *BD*, range of 0.83 to 1.84.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units*. January.

This document is one of the source documents that cites the use of the equation in Table B-1-6; however, the original source of this equation is not identified.

U. S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions*. Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600-90-003. January.

This document recommends the following:

- A range of values for soil mixing zone depth, Z_s, for tilled and untilled soil; however, the source or basis for these values is not identified
- A default ambient air temperature of 298 K
- An average annual wind speed of 3.9 m/s; however, no source or reference for this value is identified.

U.S. EPA. 1993. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions*. External Review Draft. Office of Research and Development. Washington, D.C. November.

This document is one of the reference source documents for the equation in Table B-1-6; however, the original reference for this equation is not identified.

This document also presents the following:

- A range of values for soil mixing depth, Z_s, for tilled and untilled soil; however, the original source of these values is not identified.
- COPC-specific Kd_s values that were used to establish a range (2 to 280,000 [mL water/g soil]) of Kd_s values for inorganic COPCs
- A "relatively narrow range" for soil bulk density, *BD*, of 1.2 to 1.7 (g soil/cm^3 soil)

U.S. EPA. 1994. *Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities*. April 15.

U.S. EPA. 1994a. *Estimating Exposure to Dioxin-Like Compounds. Volume III: Site-specific Assessment Procedures.* External Review Draft. Office of Research and Development. Washington, D.C. EPA/600/6-88/005Cc. June.

This document is the source of values for soil mixing zone depth, Z_s, for tilled and untilled soil, as cited in U.S. EPA (1993).

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Waste. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document recommends a default soil density, *BD*, value of 1.5 (g soil/cm^3 soil), based on a mean value for loam soil that is taken from Carsel, Parrish, Jones, Hansen, and Lamb (1988).

Weast, R.C. 1980. *Handbook of Chemistry and Physics*. 61st Edition. CRC Press, Inc. Cleveland, Ohio.

This document is cited by NC DEHNR (1997) as the source recommended values for viscosity of air, μ_a, and density of air, ρ_a.

TABLE B-3-7

FORAGE AND SILAGE CONCENTRATION DUE TO DIRECT DEPOSITION (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Description

This equation calculates the COPC concentration in forage and silage (aboveground vegetation) due to wet and dry deposition of COPCs onto plant surfaces. The limitations and uncertainty introduced in calculating this variable include the following:

(1) Variables *Q*, *Dydp*, and *Dywp* are *COPC*- and site-specific. Uncertainties associated with these variables are site-specific.

(2) In calculating the variable *Fw*, values of *r* assumed for most organic compounds—based on the behavior of insoluble polystyrene microspheres tagged with radionuclides— may accurately represent the behavior of organic compounds under site-specific conditions.

(3) The empirical relationship used to calculate the variable *Rp*, and the empirical constant for use in the relationship, may not accurately represent site-specific silage types.

(4) The recommended procedure for calculating the variable *kp* does not consider chemical degradation processes. This conservative approach contributes to the possible overestimation of plant concentrations.

(5) The harvest yield (*Yh*) and area planted (*Ah*) values used to estimate the variable *Yp* may not reflect site-specific conditions.

Equation

$$Pd = \frac{1000 \cdot [Q \cdot (1 - F_v) \cdot [Dydp + (Fw \cdot Dywp)] \cdot Rp \cdot [1.0 - \exp(-kp \cdot Tp)]}{Yp \cdot kp}$$

For mercury modeling

$$Pd = \frac{1000 \cdot (0.48Q) \cdot (1 - F_v) \cdot [Dydp + (Fw \cdot Dywp)] \cdot Rp \cdot [1.0 - \exp(-kp \cdot Tp)]}{Yp \cdot kp}$$

Forage and silage concentration due to direct deposition is calculated using *0.48Q* for total mercury and $F_v = 0.85$ in the mercury modeling equation. The calculated *Pd* value is apportioned into the divalent and methyl mercury forms based on the 78% divalent mercury (Hg^{2+}) and 22% methyl mercury (MHg) speciation split in aboveground produce and forage.

$Pd(Hg^{2+}) = 0.78\,Pd$

$Pd(Mhg) = 0.22\,Pd$

Variable	Description	Units	Value
Pd	Concentration of COPC in forage and silage due to direct deposition	mg COPC/kg DW	

TABLE B-3-7

FORAGE AND SILAGE CONCENTRATION DUE TO DIRECT DEPOSITION
(CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Description	Units	Value
1000	Units conversion factor	mg/g	
Q	COPC-specific emission rate	g/s	**Varies** This value is COPC- and site-specific, and is determined by air dispersion modeling. See Chapters 2 and 3 for guidance regarding the calculation of this variable. Uncertainties associated with this variable are site-specific.
Dydp	Unitized yearly average dry deposition from particle phase	s/m^2-yr	**Varies** This variable is COPC- and site-specific and is determined by air dispersion modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.

Variable	Description	Units	Value
Fw	Fraction of COPC wet deposition that adheres to plant surfaces	unitless	**0.2 for anions** **0.6 for cations and most organics** U.S. EPA OSW recommends using the chemical class-specific values of 0.2 for anions and 0.6 for cations and most organics and estimated by U.S. EPA (1994b) and U.S. EPA (1995). These values are the best available information, based on a review of the current scientific literature, with the following exception: U.S. EPA OSW recommends using an *Fw* value of 0.2 for the three organic COPCs that ionize to anionic forms. These include (1) 4-chloroaniline, (2) n-nitrosodiphenylamine, and (3) n-nitrosodi-n-proplyamine (see Appendix A-3). The values estimated by U.S. EPA (1994b) and U.S. EPA (1995) are based on information presented in Hoffman, Thiessen, Frank, and Blaylock (1992), which presented values for a parameter (*r*) termed the "interception fraction." These values were based on a study in which soluble radionuclides and insoluble particles labeled with radionuclides were deposited onto pasture grass via simulated rain. The parameter (*r*) is defined as "the fraction of material in rain intercepted by vegetation and initially retained" or, essentially, the product of *Rp* and *Fw,* as defined: $r = Rp \cdot Fw$ The *r* values developed by Hoffman, Thiessen, Frank, and Blaylock (1992) were divided by an *Rp* value of 0.5 for forage (U.S. EPA 1994b). The *Fw* values developed by U.S. EPA (1994b) are 0.2 for anions and 0.6 for cations and insoluble particles. U.S. EPA (1994b) and U.S. EPA (1995) recommends using the *Fw* value calculated by using the *r* value for insoluble particles to represent organic compounds; however, no rationale for this recommendation is provided. Interception values (*r*)—as defined by Hoffman, Thiessen, Frank, and Blaylock (1992)—have not been experimentally determined for aboveground produce. Therefore, U.S. EPA (1994b) and U.S. EPA (1995) apparently defaulted and assumed that the *Fw* values calculated for pasture grass (similar to forage) also apply to aboveground produce. The rationale for this recommendation is not provided. Uncertainties associated with this variable include the following: (1) Values of *r* developed experimentally for pasture grass may not accurately represent aboveground produce-specific *r* values. (2) Values of *r* assumed for most organic compounds, based on the behavior of insoluble polystryene microspheres tagged with radionuclides, may not accurately represent the behavior of organic compounds under site-specific conditions.

Variable	Description	Units	Value
F_v	Fraction of COPC air concentration in vapor phase	unitless	**0 to 1** This variable is COPC-specific. Discussion of this variable and COPC-specific values is presented in Appendix A-3. This range is based on values presented in Appendix A-3. Values are also presented in U.S. EPA (1994b) and NC DEHNR (1997). F_v was calculated using an equation presented in Junge (1977) for all organic COPCs, including PCDDs and PCDFs. U.S. EPA (1994c) states that $F_v = 0$ for all metals (except mercury). The following uncertainties are associated with this variable: (1) It is based on the assumption of a default S_T value for background plus local sources, rather than an S_T value for urban sources. If a specific site is located in an urban area, the use of the latter S_T value may be more appropriate. Specifically, the S_T value for urban sources is about one order of magnitude greater than that for background plus local sources, and it would result in a lower calculated F_v value; however, the F_v value is likely to be only a few percent lower. (2) According to Bidleman (1988), the equation used to calculate F_v assumes that the variable c (Junge constant) is constant for all chemicals; however, the value of c depends on the chemical (sorbate) molecular weight, the surface concentration for monolayer coverage, and the difference between the heat of desorption from the particle surface and the heat of vaporization of the liquid phase sorbate. To the extent that site- or COPC-specific conditions may cause the value of c to vary, uncertainty is introduced if a constant value of c is used to calculate F_v.
Dywp	Unitized yearly average wet deposition from particle phase	s/m^2-yr	**Varies** This variable is COPC- and site-specific, and is determined by air dispersion modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.

TABLE B-3-7

FORAGE AND SILAGE CONCENTRATION DUE TO DIRECT DEPOSITION (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Description	Units	Value
Rp	Interception fraction of the edible portion of plant	unitless	**Forage: 0.5** **Silage: 0.46** U.S. EPA OSW recommends the use of these default *Rp* values because it represents the most current information available; specifically, productivity and relative ingestion rates. As summarized in Baes, Sharp, Sjoreen, and Shor (1984), experimental studies of pasture grasses identified a correlation between initial *Rp* values and productivity (standing crop biomass [*Yp*]) (Chamberlain 1970): $Rp = 1 - e^{-\gamma \cdot Yp}$ where Rp = Interception fraction of the edible portion of plant (unitless) γ = Empirical constant. Chamberlain (1970) presents a range of 2.3 to 3.3; Baes, Sharp, Sjoreen, and Shor (1984) uses 2.88, the midpoint for pasture grasses. Yp = Yield or standing crop biomass (productivity) (kg DW/m^2) Baes, Sharp, Sjoreen, and Shor (1984) proposed using the same empirical relationship developed by Chamberlain (1970) for other vegetation classes. Class-specific estimates of the empirical constant, γ, were developed by forcing an exponential regression equation through several points, including average and theoretical maximum estimates of *Rp* and *Yp* (Baes, Sharp, Sjoreen, and Shor 1984) . The class-specific *Rp* estimates were then weighted, by relative ingestion of each class, to arrive at the weighted average *Rp* value of 0.5 for forage and 0.46 for silage. U.S. EPA (1994b) and U.S. EPA (1995) recommend a weighted average *Rp* value of 0.05. However, the relative ingestion rates used in U.S. EPA (1994b) and U.S. EPA (1995) to weight the average *Rp* value were derived from U.S. EPA (1992) and U.S. EPA (1994b). The most current guidance available for ingestion rates of homegrown produce is the 1997 *Exposure Factors Handbook* (U.S. EPA 1997). The default *Rp* values of 0.5 for forage and 0.46 for silage were weighted by relative ingestion rates of homegrown exposed fruit and exposed vegetables found in U.S. EPA (1997). Uncertainties associated with this variable include the following: (1) The empirical relationship developed by Chamberlain (1970) on the basis of a study of pasture grass may not accurately represent aboveground produce. (2) The empirical constants developed by Baes, Sharp, Sjoreen, and Shor (1984) for use in the empirical relationship developed by Chamberlain (1970) may not accurately represent site-specific mixes of aboveground produce.

Variable	Description	Units	Value
kp	Plant surface loss coefficient	yr^{-1}	**18** This value is site-specific. U.S. EPA (1990) identified several processes—including wind removal, water removal, and growth dilution—that reduce the amount of COPC that has been deposited onto plant surfaces. The term *kp* is a measure of the amount of COPC lost to these physical processes over time. U.S. EPA (1990) cites Miller and Hoffman (1983) for the following equation used to estimate *kp*: $kp = (\ln 2 / t_{1/2}) \cdot 365$ days/year where $t_{1/2}$ = half-time (days) Miller and Hoffman (1983) report half-time values ranging from 2.8 to 34 days for a variety of COPCs on herbaceous vegetation. These half-time values converted to *kp* values of 7.44 to 90.36 yr^{-1}. U.S. EPA (1993) and U.S. EPA (1994b) recommend a *kp* value of 18, based on a generic 14-day half-time, corresponding to physical processes only. The 14-day half-time is approximately the midpoint of the range (2.8 to 34 days) estimated by Miller and Hoffman (1983). U.S. EPA OSW recommends the use of the previously identified *kp* value of 18; this *kp* value selected is the midpoint of a possible range of values. Based on this range (7.44 to 90.36), plant concentrations could range from about 1.8 times higher to about 48 times lower than the plant concentrations, based on a *kp* value of 18. Uncertainties associated with this variable include the following: (1) Calculation of *kp* does not consider chemical degradation processes. The addition of chemical degradation processes would decrease half-times and thereby increase *kp* values; plant concentration decreases as *kp* increases. Therefore, use of a *kp* value that does not consider chemical degradation processes is conservative. (2) The half-time values reported by Miller and Hoffman (1983) may not accurately represent the behavior of compounds on aboveground produce. (3) Based on this range (7.44 to 90.36), plant concentrations could range from about 1-8 times higher to about 5 times lower than the plant concentrations, based on a *kp* value of 18.

Variable	Description	Units	Value
Tp	Length of plant exposure to deposition per harvest of edible portion of plant	yr	**Forage: 0.12** **Silage: 0.16** This variable is site-specific. U.S. EPA OSW recommends the use of these default values in the absence of site-specific information. U.S. EPA (1990), U.S. EPA (1994b), and NC DEHNR (1997) recommended treating *Tp* as a constant, based on the average periods between successive hay harvests and successive grazing. For forage, the average of the average period between successive hay harvests (60 days) and the average period between successive grazing (30 days) is used (that is, 45 days). *Tp* is calculated as follows: $Tp = (60\text{ days} + 30\text{ days})/2 \div 365\text{ days/yr} = 0.12\text{ yr}$ These average periods are from Belcher and Travis (1989), and are used when calculating the COPC concentration in cattle forage. When calculating the COPC concentration in silage fed to cattle, the average period between successive hay harvests (60 days) is used (Belcher and Travis 1989). *Tp* is calculated as follows: $Tp = 60\text{ days} \div 365\text{ days/year} = 0.16\text{ year}$ The following uncertainty is associated with this variable: The use of hay harvest cycles to estimate silage *Tp* values may underestimate COPC uptakes if silage types differ significantly from hay and have longer actual harvest cycles (for example, if grains or other feeds with longer harvest cycles are used as silage). This underestimation will increase as actual harvest cycles increase, up to about 3 months. Beyond that time frame, if the *kp* value remains unchanged at 18, higher *Tp* values will have little effect on predicted COPC concentrations in plants.

Variable	Description	Units	Value
Yp	Yield or standing crop biomass of the edible portion of the plant	kg DW/m^2	**Forage: 0.24** **Silage: 0.8** This variable is site-specific. U.S. EPA OSW recommends the use of these default values in the absence of site-specific information. U.S. EPA (1990) states that the best estimate of *Yp* is productivity, which Baes, Sharp, Sjoreen, and Shor (1984) and Shor, Baes, and Sharp (1982) define as follows: $$Yp \approx Yh_i / Ah_i$$ where Yh_i = Harvest yield of *i*th crop (kg DW) Ah_i = Area planted to crop i (m^2) U.S. EPA (1994b) and NC DEHNR (1997) recommend using either previously calculated *Yp* values or the equation presented above to calculate a *Yp* value. U.S. EPA OSW recommends that the forage *Yp* value be calculated as a weighted average of pasture grass and hay *Yp* values. Weights (0.75 for forage and 0.25 for hay) are based (1) on the fraction of a year during which cattle are assumed to be pastured and eating grass (9 mo/yr), and (2) the fraction of a year during which cattle are assumed to not be pastured and to be fed hay (3 mo/yr). An unweighted *Yp* value for pasture grass of 0.15 kg DW/m^2 is assumed (U.S. EPA 1994b). An unweighted *Yp* value for hay of 0.5 kg DW is calculated by the above equation, using the following dry harvest yield (*Yh*) and area harvested (*Ah*) values: *Yh* = $1.22 \times 10^{+11}$ kg DW; from 1993 U.S. average wet weight *Yh* of 1.35×10^{11} kg (USDA 1994) and conversion factor of 0.9 (Agricultural Research Service 1994) *Ah* = $2.45 \times 10^{+11}$ m^2; from 1993 U.S. average for hay (USDA 1994). The unweighted pasture grass and hay *Yp* values are multiplied by 3/4 and 1/4, respectively. They are then added to calculate the weighted forage *Yp* of 0.24 kg DW. U.S. EPA recommends that a production weighted U.S. average *Yp* of 0.8 be assumed for silage (Shor, Baes, and Sharp 1982). The following uncertainty is associated with this variable: The harvest yield (*Yh*) and area planted (*Ah*) may not reflect site-specific conditions. This may under- or overestimate *Yp*.

REFERENCES AND DISCUSSION

Agricultural Research Service. 1994. Personal communication regarding the dry weight fraction value for hay between G.F. Fries, and Glenn Rice and Jennifer Windholz, U.S. EPA Office of Research and Development. March 22.

This communication is cited by NC DEHNR (1997) for the fraction of 0.9 used to convert wet weight to dry weight for hay.

Baes, C.F., R.D. Sharp, A.L. Sjoreen, and R.W. Shor. 1984. *Review and Analysis of Parameters and Assessing Transport of Environmentally Released Radionuclides through Agriculture.* ORNL-5786. Oak Ridge National Laboratory. Oak Ridge, Tennessee. September.

This document proposes using the empirical relationship developed by Chamberlain (1970) (see reference and equation below) that identifies a correlation between initial Rp values and productivity (standing crop biomass [*Yp*]). It uses this relationship to calculate *Rp values* for forage and silage.

Belcher, G.D., and C.C. Travis. 1989. *Modeling Support for the RURA and Municipal Waste Combustion Projects: Final Report on Sensitivity and Uncertainty Analysis for the Terrestrial Food Chain Model.* Interagency Agreement No. 1824-A020-A1, Office of Risk Analysis, Health and Safety Research Division, Oak Ridge National Laboratory. Oak Ridge, Tennessee. October.

This document recommends *Tp* values based on the average period between successive hay harvests and successive grazing.

Bidleman, T.F. 1988. "Atmospheric Processes." *Environmental Science and Technology.* Volume 22. Number 4. Pages 361-367.

For discussion, see References and Discussion, Table B-1-1.

Chamberlain, A.C. 1970. "Interception and Retention of Radioactive Aerosols by Vegetation." *Atmospheric Environment.* 4:57 to 78.

Experimental studies of pasture grasses identified a correlation between initial *Rp* values and productivity (standing crop biomass [*Yp*]):

$$Rp = 1 - e^{-\gamma \, Yp}$$

where

γ = Empirical constant; range provided as 2.3 to 3.3
Yp = Yield or standing crop biomass (productivity) (kg DW/m^2)

Hoffman, F.O., K.M. Thiessen, M.L. Frank, and B.G. Blaylock. 1992. "Quantification of the Interception and Initial Retention of Radioactive Contaminants Deposited on Pasture Grass by Simulated Rain." *Atmospheric Environment.* Vol. 26A, 18:3313 to 3321.

This document developed values for a parameter (*r*) that it termed "interception fraction," based on a study in which soluble gamma-emitting radionuclides and insoluble particles tagged with gamma-emitting radionuclides were deposited onto pasture grass (specifically, a combination of fescue, clover, and old field vegetation, including fescue) via simulated rain. The parameter, *r*, is defined as "the fraction of material in rain intercepted by vegetation and initially retained" or, essentially, the product of *Rp* and *Fw,* as defined for the HHRAP:

$$r = Rp \cdot Fw$$

Experimental *r* values obtained include the following:

- An *r* range of 0.006 to 0.3 for anions (based on the soluble radionuclide iodide-131 [^{131}I]; when calculating *Rp* values for anions, U.S. EPA (1994a) used the highest geometric mean *r* value (0.08) observed in the study.
- An *r* range of 0.1 to 0.6 for cations (based on the soluble radionuclide beryllium-7 [^{7}Be]; when calculating *Rp* values for cations, U.S. EPA (1994a) used the highest geometric mean *r* value (0.28) observed in the study.
- A geometric range of *r* values from 0.30 to 0.37 for IPMs ranging in diameter from 3 micrometers, to 25 micrometers labeled with ^{141}Ce, ^{95}Nb, and ^{85}Sr; when calculating *Rp* values for organics (other than three organics that ionize to anionic forms: 4-chloroaniline, n-nitrosodiphenylamine, and n-nitrosodi-n-propylamine [see Appendix A-3]). U.S. EPA (1994a) used the geometric mean *r* value for IPM with a diameter of 3 micrometers; however, no rationale for this selection is provided.

The authors concluded that, for the soluble ^{131}I anion, interception fraction (*r*) is an inverse function of rain amount, whereas for the soluble cation ^{7}Be and the IPMs, *r* depends more on biomass than on amount of rainfall. The authors also concluded that (1) the anionic ^{131}I is essentially removed with the water after the vegetation surface has become saturated, and (2) the cationic ^{7}Be and the IPMs are adsorbed to or settle out onto the plant surface. This discrepancy between the behavior of the anionic and the cationic species is consistent with a negative charge on the plant surface.

Junge, C.E. 1977. *Fate of Pollutants in Air and Water Environments, Part I.* Suffet, I.H., Ed. Wiley. New York. Pages 7-26.

Miller, C.W., and F.O. Hoffman. 1983. "An Examination of the Environmental Half-Time for Radionuclides Deposited on Vegetation." *Health Physics.* 45 (3): 731 to 744.

This document is the source of the equation used to calculate *kp*:

$$kp = (\ln 2 / t_{1/2}) \times 365 \text{ days/year}$$

where

$t_{1/2}$ = half-time (days)

The study reports half-time values ranging from 2.8 to 34 days for a variety of contaminants on herbaceous vegetation. These half-time values convert to *kp* values of 7.44 to 90.36 years^{-1}.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This a source document for the equation in Table B-3-7.

This document also recommends the following:

- *Rp* values of 0.5 (forage) and 0.46 (silage), based on the correlation from Chamberlain (1970)
- Treating *Tp* as a constant, based on the average periods between successive hay harvests and successive grazing
- Bidleman (1988) as source of equation for calculating F_v

Shor, R.W., C.F. Baes, and R.D. Sharp. 1982. *Agricultural Production in the United States by County: A Compilation of Information from the 1974 Census of Agriculture for Use in Terrestrial Food-Chain Transport and Assessment Models.* Oak Ridge National Laboratory Publication. ORNL-5786.

For discussion, see References and Discussion in Table B-2-7.

U.S. Department of Agriculture (USDA). 1994. *Vegetables 1993 Summary.* National Agricultural Statistics Service, Agricultural Statistics Board. Washington, D.C. Vg 1-2 (94).

This document is cited by NC DEHNR (1997) as the source for the average wet weight harvest yield (*Yh*) for hay.

U.S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600/6-90/003. January.

This is one of the source documents for the equation in Table B-3-7. This document also states that the best estimate of *Yp* (yield or standing crop biomass) is productivity, as defined above under Shor, Baes, and Sharp (1982).

U.S. EPA. 1993. *Review Draft Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Office of Health and Environmental Assessment. Office of Research and Development. EPA/600/AP-93/003. November.

This is one of the source documents for the equation in Table B-3-7. This document also recommends a *kp* value of 18, based on a generic 14-day half-time, corresponding to physical processes only. This 14-day half-time is approximately the midpoint of the range (2.8 to 34 days) estimated by Miller and Hoffman (1983).

U.S. EPA. 1994a. *Estimating Exposure to Dioxin-Like Compounds. Volume III: Site-Specific Assessment Procedures.* External Review Draft. Office of Research and Development. Washington, D.C. EPA/600/6-88/005Cc. June.

This document recommends an unweighted estimate of yield or standing crop biomass of 0.15 kg DW/m^2 for pasture grass.

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This is one of the source documents for the equation in Table B-3-7. This document also (1) developed and recommends *Fw* values of 0.2 for anions and 0.6 for cations and insoluble particles, based on dividing "*r*" values developed by Hoffman, Thiessen, Frank, and Blaylock (1992) and an *Rp* value of 0.5 for forage; (2) recommends *Rp* values of 0.5 (forage) and 0.46 (silage); (3) recommends a *kp* value of 18, based on a generic 14-day half-time, corresponding to physical processes only, (4) recommends treating *Tp* as a constant ,based on the average periods between successive hay harvests and successive grazing, and (5) cites Bidleman (1988) as the source of the equation for calculating F_v.

U.S. EPA. 1995. *Review Draft Development of Human Health-Based and Ecologically-Based Exit Criteria for the Hazardous Waste Identification Project.* Volumes I and II. Office of Solid Waste. March 3.

This is one of the source documents for the equation in Table B-2-6. This document also recommends (1) using the *Fw* value calculated by using the *r* value for insoluble particles (see Hoffman, Thiessen, Frank, and Blaylock 1992) to represent organic compounds; however, no rationale for this recommendation is provided, and (2) *Rp* values of 0.5 (forage) and 0.46 (silage), based on the correlation from Chamberlain (1970).

U.S. EPA. 1997. *Exposure Factors Handbook.* "Food Ingestion Factors". Volume II. SAB Review Draft. EPA/600/P-95/002F. August.

Description

This equation calculates the COPC concentration in forage and silage (aboveground vegetation) resulting from direct uptake of vapor phase COPCs onto plant surfaces.

Uncertainties associated with the use of this equation include the following:

(1) The range of values for the variable *Bv* (air-to-plant biotransfer factor) is about 19 orders of magnitude for organic COPCs. COPC-specific *Bv* values for nondioxin-like compounds may be overestimated by up to one order of magnitude, based on experimental conditions used to develop the algorithm used to estimate *Bv* values.

(2) The algorithm used to calculate values for the variable F_v assumes a default value for the parameter S_T (Whitby's average surface area of particulates [aerosols]) of background plus local sources, rather than an S_T value for urban sources. If a specific site is located in an urban area, the use of the latter S_T value may be more appropriate. The S_T value for urban sources is about one order of magnitude greater than that for background plus local sources and would result in a lower Fv value; however, the F_v value is likely to be only a few percent lower.

Equation

$$Pv = Q \cdot F_v \cdot \frac{Cyv \cdot Bv_{forage} \cdot VG_{ag}}{\rho_a}$$

For mercury modeling

$$Pv = (0.48Q) \cdot F_v \cdot \frac{Cyv \cdot Bv_{forage} \cdot VG_{ag}}{\rho_a}$$

Aboveground produce concentration due to air-to-plant transfer is calculated *0.48Q* for total mercury and $F_v = 0.85$ in the mercury modeling equation. The calculated *Pv* value is apportioned into the divalent and methyl mercury forms based on the 78% divalent mercury (Hg^{2+}) and 22% methyl mercury (MHg) speciation split in aboveground produce and forage.

$Pv\ (Hg^{2+}) = 0.78\ Pv$
$Pv\ (Mhg) = 0.22\ Pv$

Variable	Description	Units	Value
Pv	Forage and silage concentration due to air-to-plant transfer	µg COPC/g DW plant tissue (equivalent to mg/kg DW)	

TABLE B-3-8

FORAGE AND SILAGE CONCENTRATION DUE TO AIR-TO-PLANT TRANSFER (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Description	Units	Value
Q	COPC-specific emission rate	g/s	**Varies** This variable is COPC- and site-specific. See Chapters 2 and 3 for guidance regarding the calculation of this variable. Uncertainties associated with this variable are also COPC- and site-specific.
F_v	Fraction of COPC air concentration in vapor phase	unitless	**0 to 1** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values is presented in Appendix A-3. This range is based on values presented in Appendix A-3. Values are also presented in U.S. EPA (1994b) and NC DEHNR (1997). F_v was calculated using an equation presented in Junge (1977) for all organic COPCs, including PCDDs and PCDFs. U.S. EPA (1994c) states that $F_v = 0$ for all metals (except mercury). The following uncertainties are associated with this variable: (1) It is based on the assumption of a default S_T value for background plus local sources, rather than an S_T value for urban sources. If a specific site is located in an urban area, the use of the latter S_T value may be more appropriate. Specifically, the S_T value for urban sources is about one order of magnitude greater than that for background plus local sources, and it would result in a lower calculated F_v value; however, the F_v value is likely to be only a few percent lower. (2) According to Bidleman (1988), the equation used to calculate F_v assumes that the variable c (Junge constant) is constant for all chemicals; however, the value of c depends on the chemical (sorbate) molecular weight, the surface concentration for monolayer coverage, and the difference between the heat of desorption from the particle surface and the heat of vaporization of the liquid-phase sorbate. To the extent that site- or COPC-specific conditions may cause the value of c to vary, uncertainty is introduced if a constant value of c is used to calculate F_v.
Cyv	Unitized yearly average air concentration from vapor phase	μg-s/g-m^3	**Varies** This variable is COPC- and site-specific, and is determined by air dispersion modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.

TABLE B-3-8

FORAGE AND SILAGE CONCENTRATION DUE TO AIR-TO-PLANT TRANSFER (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Description	Units	Value
Bv_{forage}	Air-to-plant biotransfer factor for forage and silage	(mg COPC/g plant tissue DW)/ (mg COPC/g air)	**Varies** This variable is COPC-specific. Discussion of this variable and COPC-specific values are presented in Appendix A-3. Uncertainty associated with this variable include the following: The studies that formed the basis of the algorithm used to estimate *Bv* values were conducted on azalea leaves and grasses, and may not accurately represent *Bv* for aboveground produce other than leafy vegetables.
VG_{ag}	Empirical correction factor for forage and silage	unitless	**Forage: 1.0** **Silage: 0.5** This variable is site-specific. U.S. EPA OSW recommends the use of VG_{ag} values of 1.0 for forage and 0.5 for silage in the absence of site-specific information. U.S. EPA (1994a), U.S. EPA (1994b), and NC DEHNR (1997) recommend an empirical correction factor to reduce estimated concentrations of constituents in specific vegetation types. This factor is used to reduce estimated bulky silage concentrations, because (1) *Bv* was developed for azalea leaves, and (2) it is assumed that there is insignificant translocation of compounds deposited on the surface of specific vegetation types (such as bulky silage) to the inner parts of this vegetation. U.S. EPA (1994a) and U.S. EPA (1994b) recommends a VG_{ag} of 1.0 for pasture grass and other leafy vegetation because of a direct analogy to exposed azalea and grass leaves. Pasture grass is described as "leafy vegetation." U.S. EPA (1994a) and U.S. EPA (1994b) does not recommend a VG_{ag} value for silage. NC DEHNR (1997) recommends a VG_{ag} factor of 0.5 for bulky silage but does not present a specific rationale for this recommendation. U.S. EPA (1995) notes that a volume ratio of outer surface area volume to whole vegetation volume could be used to assign a value to VG_{ag} for silage, if specific assumptions concerning the proportions of each type of vegetation of which silage may consist of were known (for example, corn and other grains). In the absence of specific assumptions concerning hay/silage/grain intake, however, U.S. EPA (1995) recommends assuming a VG_{ag} of 0.5 for silage without rigorous justification. The following uncertainty is associated with this variable: (1) It is recommended that the VG_{ag} value of 0.5 for silage be used without vigorous justification. Depending on the composition of site-specific silage, the recommended VG_{ag} value may under- or overestimate the actual value.

Variable	Description	Units	Value
ρ_a	Density of air	g/m^3	**0.0012** This variable is site-specific. U.S. EPA OSW recommends the use of this default value in the absence of site-specific information. U.S. EPA (1990) recommends the same value, but states that it is based on a temperature of 25°C; no reference was provided. U.S. EPA (1994b) and NC DEHNR (1997) recommend this same value, but state that it was calculated at standard conditions (20°C and 1 atmosphere)(Weast 1981). A review of Weast (1986) indicates that air density varies with temperature. An air density of 1.2×10^{-03} (rounded to two significant figures) applies to both 20°C and 25°C.

REFERENCES AND DISCUSSION

Bidelman, T.F. 1988. "Atmospheric Processes." *Environmental Science and Technology.* Volume 22. Number 4. Pages 361-367

For discussion, see References and Discussion in Table B-1-1.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This is a source document for the equation in Table B-3-8. This document also recommends (1) that F_v values be based on the work of Bidleman (1988) , and (2) the use of an empirical correction factor (VG_{ag}) to reduce concentrations of COPCs in some vegetation types- (specifically, a VG_{ag} value of 0.5 is recommended for silage; however, no rationale is provided for this value). This factor is used to reduce estimated COPC concentrations in specific vegetation types, because (1) *Bv* was developed for azalea leaves, and (2) it is assumed that there is significant translocation of compounds deposited on the surface of specific vegetation types to the inner parts of this vegetation.

Riederer, M. 1990. "Estimating Partitioning and Transport of Organic Chemicals in the Foliage/Atmosphere: Discussion of a Fugacity-Based Model." *Environmental Science and Technology.* 24: 829 to 837.

This is the source of the leaf thickness used to estimate the empirical correction factor (VG_{ag}).

U.S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600/6-90/003. January.

This is one of the source documents for the equation in Table B-3-8.

U.S. EPA. 1993. *Review Draft Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combuster Emissions. Office of Health and Environmental Assessment.* Office of Research and Development. EPA-600-AP-03-003. November 10.

This document recommends reducing *Bv* values calculated by using the Bacci, Cerejeira, Gaggi, Chemello, Calamari, and Vighi (1992) algorithm by a factor of 10 based on attempts to model background concentrations. The use of this factor "made predictions [of beef concentrations] come in line with observations."

U. S. EPA 1994a. *Estimating Exposure to Dioxin-Like Compounds. Volume II: Properties, Sources, Occurrence, and Background Exposures.* External Review Draft. Office of Research and Development. Washington, D.C. EPA/600/6-88/005Cb. June.

This document recommends an empirical correction factor of 0.01 to reduce estimated vegetable concentrations, based on the assumption that there is insignificant translocation of compounds deposited on the surface of aboveground vegetation to inner parts for aboveground produce. The document provides no reference or discussion regarding the validity of this assumption.

The factor of 0.01 is based on a similar correction factor for below ground produce (VG_{ag}), which is estimated based on a ratio of the vegetable skin mass to vegetable total mass. The document assumes that the density of the skin and vegetable are equal. The document also assumes an average vegetable skin leaf based on Rierderer (1990). Based on these

assumptions, U.S. EPA (1994a) calculated VG_{ag} for carrots and potatoes of 0.09 and 0.03, respectively. By comparing these values to contamination reduction research completed by Wipf, Hourbergem Neuner, Ranalder, Vetter, and Uilleumier (1982), U.S. EPA (1994a) arrived at the recommended VG_{ag} of 0.01.

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This is one of the source documents for the equation in Table B-3-8. This document also presents a range (0.27 to 1) of F_v values for organic COPCs, calculated on the basis of Bidleman (1988); F_v for all inorganics is set equal to zero.

U.S. EPA. 1995. *Review Draft Development of Human-Health Based and Ecologically-Based Exit Criteria for the Hazardous Waste Identification Project.* Volumes I and II. Office of Solid Waste. March 3.

This document presents estimated VG_{ag} values. U.S. EPA (1995) notes that a volume ratio of outer surface area volume to whole vegetation volume could be used to assign a value to VG_{ag} for silage, if specific assumptions (concerning the proportions of each type of vegetation of which silage may consist of) were known (for example, corn and other grains). In the absence of specific assumptions concerning hay/silage/grain intake, however, U.S. EPA (1995) recommends assuming a VG_{ag} value of 0.5 for silage (for COPCs with a log K_{ow} greater than 4) without rigorous justification.

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

Weast, R.C. 1981. *Handbook of Chemistry and Physics.* 62nd Edition. Cleveland, Ohio. CRC Press.

This document is a reference for air density values.

Weast, R.C. 1986. *Handbook of Chemistry and Physics.* 66th Edition. Cleveland, Ohio. CRC Press.

This document is a reference for air density values, and is an update of Weast (1981).

Wipf, H.K., E. Hamberger, N. Neuner, U.B. Ranalder, W. Vetter, and J.P. Vuilleumier. 1982 "TCDD Levels in Soil and Plant Samples from the Seveso Area." In: *Chlorinated Dioxins and Related Compounds: Impact on the Environment.* Eds. Hutzinger, O. et al. Perganon. New York.

TABLE B-3-9

FORAGE/SILAGE/GRAIN CONCENTRATION DUE TO ROOT UPTAKE (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Description

This equation calculates the COPC concentration in forage/silage/grain (aboveground produce), due to direct uptake of COPCs from soil through plant roots. Uncertainties associated with the use of this equation include the following:

(1) The availability of site-specific information, such as meteorological data, will affect the accuracy of *Cs* estimates.

(2) Estimated COPC-specific soil-to-plant bioconcentration factors (*Br*) do not reflect site-specific conditions. This may especially be true for inorganic COPCs for which estimates of *Br* would be more accurately estimated by using site-specific bioconcentration factors rather than bioconcentration factors from Baes, Sharp, Sjoreen, and Shor (1984). Hence, U.S. EPA OSW recommends the use of plant uptake response-slope factors derived from U.S. EPA (1992) for arsenic, cadmium, selenium, nickel, and zinc.

Equation

$$Pr = Cs \cdot Br_{forage}$$

For mercury modeling, forage/silage/grain concentration due to root uptake is calculated for divalent mercury (Hg^{2+}) and methyl mercury (MHg) using their respective *Cs* and *Br* values.

$$Pr_{Hg^{2+}} = Cs_{Hg^{2+}} \cdot Br_{forage(Hg^{2+})}$$

$$Pr_{MHg} = Cs_{MHg} \cdot Br_{forage(MHg)}$$

Variable	Description	Units	Value
Pr	Concentration of COPC in forage/silage/grain due to root uptake	mgCOPC/kg DW plant tissue	
Cs	Average soil concentration over exposure duration	mg/kg	**Varies** This value is COPC and site-specific, and should be calculated using the equation in Table B-3-1. Uncertainties associated with this variable are site-specific.

TABLE B-3-9

FORAGE/SILAGE/GRAIN CONCENTRATION DUE TO ROOT UPTAKE (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Description	Units	Value
Br_{forage}	Plant-soil bioconcentration factor for forage, silage, and grain	unitless [(mg COPC/kg plant DW)/ (mg COPC/kg soil)]	**Varies** This variable is COPC-specific. Discussion of this variable and COPC-specific values are presented in Appendix A-3. Uncertainties associated with this variable include the following: (1) Estimates of *Br* for some inorganic COPCs, based on plant uptake response slope factors, may be more accurate than those based on *BCF*s from Baes, Sharp, Sjoreen, and Shor (1984). (2) U.S. EPA OSW recommends that uptake of organic COPCs from soil and transport of the COPCs to aboveground plant parts be calculated on the basis of a regression equation developed in a study of the uptake of 29 organic compounds. This regression equation, developed by Travis and Arms (1988), may not accurately represent the behavior of all classes of organic COPCs under site-specific conditions.

REFERENCES AND DISCUSSION

Baes, C.F. R.D. Sharp, A.L. Sjoreen, and R.W. Shor. 1984. *Review and Analysis of Parameters and Assessing Transport of Environmentally Released Radionuclides Through Agriculture.* ORNL-5786. Oak Ridge National Laboratory, Oak Ridge, Tennessee. September.

This document presents inorganic-specific transfer factors (*Br*) for both vegetative (*Bv*) portions of food crops and nonvegetative (reproductive—fruits, seeds, and tubers) portions (Br) of food crops. These bioconcentration factors were developed based on review and compilation of a wide variety of measured, empirical, and comparative data.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This is a source document for the equation in Table B-3-9.

Travis, C.C., and A.O. Arms. 1988. "Bioconcentration of Organics in Beef, Milk, and Vegetation." *Environmental Science and Technology.* 22:271 to 274.

This document developed the following regression equation relating soil-to-plant bioconcentration factor (*Br*) to K_{ow}, based on varied soil and plant concentration data:

$$\log Br = 1.588 - 0.578 \cdot \log K_{ow}$$

U.S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustion Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA/000/6-90/003. January.

This is one of the source documents for the equation in Table B-3-9. This document also notes:

(1) the uptake of organic compounds from soil and transport of these compounds into forage,
(2) and that grain is dependent on the solubility of compounds in water, which is inversely proportional to the octanol-water partition coefficient (K_{ow}).

U.S. EPA. 1992. *Technical Support Document for Land Application of Sewage Sludge.* Volumes I and II. Office of Water. Washington, D.C. EPA 822/R-93-001a.

Source of plant uptake response factors for arsenic, cadmium, nickel, selenium, and zinc. Plant uptake response factors can be converted to BCFs by multiplying the plant uptake response factor by a factor of 2.

U.S. EPA. 1995. *Review Draft Development of Human Health Based and Ecologically Based Exit Criteria for the Hazardous Waste Identification Project. Volumes I and II.* Office of Solid Waste. March 3.

This document recommends using the bioconcentration factors *Bv* and *Br* from Baes, Sharp, Sjoreen, and Shor (1984) for calculating the uptake of inorganics into vegetative and nonvegetative growth, respectively.

TABLE B-3-9

FORAGE/SILAGE/GRAIN CONCENTRATION DUE TO ROOT UPTAKE (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

(Page 4 of 4)

Although most bioconcentration factors employed in this document came from Baes, Sharp, Sjoreen, and Shor (1984), values for some inorganics were apparently obtained from plant uptake response slope factors. These uptake response slope factors were calculated from field data, such as metal loading rates and soil metal concentrations. However, the methodologies and references used to calculate the uptake response slope factors are not clearly identified.

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

BEEF CONCENTRATION DUE TO PLANT AND SOIL INGESTION (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Description

This equation first estimates the daily amount of COPCs by cattle through the ingestion of contaminated plant and soil material. The equation then recommends the use of biotransfer factors to transform the daily animal intake of a COPC (mg COPC/day) into an animal COPC tissue concentration (mg COPC/kg FW tissue).

The limitations and uncertainty introduced in calculating this variable include the following:

(1) Variables P_i and Cs are COPC- and site-specific. Uncertainties associated with these variables are site-specific.
(2) Uncertainties associated with the variables F_i, Qs, and Qp_i are expected to be minimal.
(3) The use of a single Ba_{beef} value for each COPC may not accurately reflect site-specific conditions. It is not clear whether the default values are likely to under - or overestimate A_{beef}.

Based on the information below, A_{beef} is dependent on the concentrations of COPCs estimated in plant feeds and soil, and the biotransfer factor estimated for each constituent.

Equation

$$A_{beef} = \left(\sum (F_i \cdot Qp_i \cdot P_i) + Qs \cdot Cs \cdot Bs \right) \cdot Ba_{beef} \cdot MF$$

For mercury modeling, beef concentration due to plant and soil ingestion is calculated for divalent mercury (Hg^{2+}) and methyl mercury (MHg) using their respective P_i, Cs, and Ba_{beef} values.

Variable	Description	Units	Value
A_{beef}	Concentration of COPC in beef	mg COPC/kg FW tissue	
F_i	Fraction of plant type (i) grown on contaminated soil and ingested by the animal	unitless	1 This variable is site- and plant type-specific. Plant types for cattle are typically identified as grain, forage, and silage. U.S. EPA OSW recommends that a default value of 1.0 be used for all plant types when site-specific information is not available. This is consistent with U.S. EPA (1990), U.S. EPA (1994a), U.S. EPA (1994b) and NC DEHNR (1997), which recommend that 100 percent of the plant materials ingested by cattle be assumed to have been grown on soil contaminated by emissions. The following uncertainty is associated with this variable: (1) 100 percent of the plant materials eaten by cattle are assumed to be grown on soil contaminated by emissions. This may overestimate A_{beef}.

Variable	Description	Units	Value
Qp_i	Quantity of plant type (*i*) ingested by the animal per day	kg DW plant/day	**Forage: 8.8** **Silage: 2.5** **Grain: 0.47** This variable is site- and plant type-specific; plant types for cattle are typically identified as grain, forage, and silage. U.S. EPA OSW recommends that cattle raised by subsistence beef farmers be evaluated by using the following values for *Qp*: forage (8.8), silage (2.5), and grain (0.47). These values are consistent with U.S. EPA (1990), U.S. EPA (1994c), and NC DEHNR (1997). Although not typically recommended by U.S. EPA —because subsistence beef farmers rely on a higher percentage of forage and silage to feed cattle, whereas typical beef farmers rely on greater amounts of grain to feed cattle—it may be appropriate in site-specific cases to evaluate cattle raised by typical beef farmers by using the following values for *Qp*: forage (3.8), silage (1.0), and grain (3.8). These values are also consistent with U.S. EPA (1990), U.S. EPA (1994c), and NC DEHNR (1997). The reference documents cite Boone, Ng, and Palms (1981), NAS (1987), McKone and Ryan (1989), and Rice (1994) as primary references for plant ingestion rates. Uncertainties introduced by this variable include the following: (1) The recommended daily grain ingestion rate of 0.47 kg dry weight (DW)/day is calculated indirectly from (1) a recommended total daily dry matter intake of 11.8 kg DW plant/day, based on NAS (1987) and McKone and Ryan (1989), as cited in EPA (1990), and (2) daily ingestion rates of forage (8.8 kg/day) and silage (2.5 kg DW/day), recommended by Boone, Ng, and Palms (1981). However, Boone, Ng, and Palms (1981) recommended an alternative daily grain ingestion rate of 1.9 kg DW/day, about four times higher than the rate recommended by U.S. EPA . As shown in Equations in Tables B-3-7 through B-3-9, the concentrations of COPCs in forage, silage, and grain are calculated similarly. Therefore, the relative amounts of forage, silage, and grain ingested daily have a limited effect on the intake of COPCs, if the total daily intake of dry matter is held constant. Therefore, limited uncertainty is introduced. (2) The daily ingestion rates (total and plant type-specific) recommended may not accurately represent site-specific or local conditions. Therefore, A_{beef} may be under- or overestimated, but limited degree.

Variable	Description	Units	Value
P_i	Concentration of COPC in plant type *(i)* ingested by the animal	mg/kg DW	**Varies** This variable is COPC-, site-, and plant type-specific; plant types for cattle are typically identified as grain, forage, and silage. Values for *Pd*, *Pv*, and *Pr* are calculated by using the equations in Tables B-3-7, B-3-8, and B-3-9; and then summed for each plant type to determine P_i. Uncertainties introduced by this variable include the following: (1) Some of the variables in the equations in Tables B-3-7, B-3-8, and B-3-9—including *Cs, Cyv, Q, Dydp*, and *Dywp*—are COPC- and site-specific. Uncertainties associated with these variables are site-specific. (2) In the equation in Table B-3-7, uncertainties associated with other variables include the following: F_w (values for organic compounds estimated on the basis of the behavior of polystyrene microspheres), *Rp* (estimated on the basis of a generalized empirical relationship), *kp* (estimation process does not consider chemical degradation), and *Yp* (estimated on the basis of national harvest yield and area planted values). All of these uncertainties contribute to the overall uncertainty associated with P_i. (3) In the equation in Table B-3-8, COPC-specific *Bv* values for nondioxin-like compounds may be overestimated by up to one order of magnitude, based on experimental conditions used to develop the algorithm to estimate *Bv* values. (4) In the equation in Table B-3-9, COPC-specific plant-soil biotransfer factors (*Br*) may not reflect site-specific conditions. This may be especially true for inorganic COPCs for which estimates of *Br* would be more accurately estimated by using plant uptake response slope factors.
Qs	Quantity of soil ingested by the animal	kg/day	**0.5** This variable is site-specific. U.S. EPA OSW recommends that the soil ingestion rate of 0.5 kg/day be used. This is consistent with NC DEHNR (1997) and U.S. EPA (1994c), which cite USDA (1994), Rice (1994), and NAS (1987). These references are described below. Although not typically recommended by U.S. EPA —because subsistence beef farmers rely on a higher percentage forage to feed cattle, whereas typical beef farmers rely on greater amounts of grain to feed cattle—it may be appropriate in site-specific cases to evaluate cattle raised by typical beef farmers by using a value for *Qs* of 0.25 kg/day. This is consistent with NC DEHNR (1997), which cites Rice (1994) as the source of this value. These references are described below. Uncertainties introduced by this variable include the following: (1) The recommended soil ingestion rate may not accurately represent site-specific or local conditions. However, any differences between the recommended value and site-specific or local soil ingestion rates are expected to be small. Therefore, any uncertainty introduced is also expected to be limited.

TABLE B-3-10

BEEF CONCENTRATION DUE TO PLANT AND SOIL INGESTION (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Description	Units	Value
Cs	Average soil concentration over exposure duration	mg COPC/kg soil	**Varies** This variable is COPC- and site-specific, and should be calculated by using the equation in Table B-3-1. Uncertainties introduced by this variable are site-specific.
Bs	Soil bioavailability factor	unitless	**1.0** The soil bioavailability factor, *Bs,* can be thought of as the ratio between bioconcentration (or biotransfer) factors for soil and vegetation for a given contaminant. The efficiency of transfer from soil may differ from efficiency or transfer from plant material for some COPCs. If the transfer efficiency is lower for soils, than this ratio would be less than 1.0. If it is equal or greater than that of vegetation, the *Bs* would be equal to or greater than 1.0. Since there is not enough data regarding bioavailability from soil, U.S. EPA OSW recommends a default value of 1.0 for *Bs,* until more COPC data becomes available for this parameter. There is a fair amount of uncertainty associated with the use of this default value, because some COPCs may be much less bioavailable from soil than from plant tissues.
Ba_{beef}	Biotransfer factor for beef	day/kg FW tissue	**Varies** This variable is COPC-specific. Discussion of this variable and COPC-specific values are presented in Appendix A-3. Ba_{beef} is defined as the ratio of the COPC concentration in animal tissue (mg COPC/kg animal tissue) to the daily intake of the COPC (mg COPC/day) by the animal. Uncertainties introduced by this variable include the following: (1) U.S. EPA OSW recommends that Ba_{beef} values for organic COPCs other than dioxins and furans be calculated by using the regression equation developed on the basis of a study of 29 organic compounds. Values calculated by using this regression equation may not accurately represent the behavior of organic COPCs under site-specific conditions. Therefore, estimates of Ba_{beef} and, therefore, A_{beef} may be under- or overestimated to some degree. (2) U.S. EPA OSW recommends use of Ba_{beef} values for dioxins and furans developed by U.S. EPA (1995). These values were developed by using experimental data for a single cow from McLachlan, Thoma, Reissinger, and Hutzinger (1990). The uptake and distribution of dioxins and furans in this single animal may not accurately represent the behavior of these compounds in livestock under site-specific conditions. Therefore, Ba_{beef}, and A_{beef} value may be under- or overestimated to some degree. (3) U.S. EPA recommended that Ba_{beef} values for metals be calculated by using single COPC-specific uptake factors developed by Baes, Sharp, Sjoreen, and Shor (1984). These uptake factors may not accurately represent the behavior of inorganic COPCs under site-specific conditions; therefore, Ba_{beef} and, therefore, A_{beef} value may be under- or overestimated to some degree.

TABLE B-3-10

BEEF CONCENTRATION DUE TO PLANT AND SOIL INGESTION (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Description	Units	Value
MF	Metabolism factor	unitless	**0.01 and 1.0** This variable is COPC-specific. Based on a study by Ikeda et al. (1980), U.S. EPA (1995a) recommended using a metabolism factor to account for metabolism in animals to offset the amount of bioaccumulation suggested by biotransfer factors. MF applies only to beef, milk, and pork. It does not apply to direct exposures to air, soil, or water, or to ingestion of produce, chicken, or fish. U.S. EPA (1995b) recommended an MF of 0.01 for bis(2-ethylhexyl)phthalate (BEHP) and 1.0 for all other contaminants.

REFERENCES AND DISCUSSION

Baes, C.F., R.D. Sharp, A.L. Sjoreen, and R.W. Shor. 1984. "Review and Analysis of Parameters and Assessing Transport of Environmentally Released Radionuclides Through Agriculture." Oak Ridge National Laboratory, Oak Ridge, Tennessee.

U.S. EPA (1994c) recommends Baes Sharp, Sjoreen, and Shor (1984) as a source of Ba_{beef} values for inorganics.

Boone, F.W., Yook C. Ng, and John M. Palms. 1981. "Terrestrial Pathways of Radionuclide Particulates." *Health Physics*, Vol. 41, No. 5, pp. 735-747. November.

This document is identified as a source of plant ingestion rates. Boone, Ng, and Palms (1981) reports forage, grain, and silage ingestion rates of 8.8, 1.9, and 2.5 kg DW/day, respectively, for subsistence beef cattle.

Ikeda, G.J., P.P. Sapenza, and J.L. Couvillion. 1980. "Comparative distribution, excretion, and metabolism of di(2-ethylhexyl)phthalate in rats, dogs, and pigs." *Food Cosmet. Toxicology.* 18:637- 642.

McKone, T.E., and P.B. Ryan. 1989. *Human Exposures to Chemicals Through Food Chains: An Uncertainty Analysis.* Livermore, California: Lawrence Livermore National Laboratory Report. UCRL-99290.

This document is cited as a source of plant ingestion rates. According to U.S. EPA (1990), McKone and Ryan (1989) report an average total subsistence ingestion rate of 12 kg DW/day for the three plant feeds, which is consistent with the total recommended by other guidance documents for subsistence cattle (that is, forage, grain, and silage total of 11.8 kg DW/day).

McLachlan, M.S., H. Thoma, M. Reissinger, and O. Hutzinger. 1990. "PCDD/F in an Agricultural Food Chain, Part 1: PCDD/F Mass Balance of a Lactating Cow." Chemosphere, Vol. 20, Nos. 7-9, pp. 1013-1020.

This document is identified as a source of cow milk experimental data used in the U.S. EPA (1992) dioxin document to calculate bioconcentration factors with units of kilograms feed/kilogram tissue. As described for U.S. EPA (1995) below, these bioconcentration factors were converted to Ba_{beef} values.

National Academy of Sciences (NAS). 1987. *Predicting Feed Intake of Food-Producing Animals.* National Research Council, Committee on Animal Nutrition, Washington, D.C.

This document is identified as a source of food ingestion rates. NC DEHNR (1997) and U.S. EPA (1994c) note that NAS (1987) reports a daily dry matter intake that is 2 percent of an average beef cattle body weight of 590 kilograms. This results in a daily total intake rate of 11.8 kg DW/day, and the daily soil ingestion rate of approximately 0.5 kg soil/day (based on USDA [1994]).

NC DEHNR. 1997. *Final NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is a reference source for the equation in Table B-3-10. This document also recommends the following:

- Forage, grain, and silage ingestion rates of 3.8, 3.8, and 1.0 kg DW/day, respectively, for typical farmer beef cattle, based on Rice (1994)
- Use of regression equation from Travis and Arms (1988) to calculate biotransfer factors for beef, Ba_{beef}

TABLE B-3-10

BEEF CONCENTRATION DUE TO PLANT AND SOIL INGESTION (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

NC DEHNR (1997) recommends forage, grain, and silage ingestion rates of 3.8, 3.8, and 1.0 kg dry weight/day, respectively, for typical farmer beef cattle. NC DEHNR (1997) reports Rice (1994) as a references for these variable.

Travis, C.C., and A.D. Arms. 1988. "Bioconcentration of Organics in Beef, Milk, and Vegetation." *Environmental Science and Technology.* 22:271-274

For organic COPCs, U.S. EPA (1990 and 1994c):

(1) recommend that the regression equation from this document (see below) be used to calculate biotransfer factors for beef (Ba_{beef})
(2) report a positive correlation between log K_{ow} and Ba_{beef} values, and
(3) recommend using log K_{ow} to calculate Ba_{beef} values for organic compounds, as presented in the following regression equation:

$$\log Ba_{beef} = -7.6 + \log K_{ow}$$

where

Ba_{beef}	=	Biotransfer factor for beef (day/kg)
K_{ow}	=	Octanol-water partition coefficient (unitless) (see Appendix A-3)

This document recommends fat content values for beef and milk of 25 and 3.08 percent, respectively.

U.S. Department of Agriculture (USDA). 1994. Personal Communication Between G.F. Fries, and Glenn Rice and Jennifer Windholtz, U.S. Environmental Protection Agency, Office of Research and Development. Agricultural Research Service. March 22.

NC DEHNR (1997) and U.S. EPA (1994c) note that this reference reports soil ingestion for cattle to be 4 percent of the total daily dry matter intake.

U.S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA-600-90-003. January.

This document recommends an F_i value of 1; this value assumes that 100 percent of the plant materials ingested by cattle have been grown on soil contaminated by emissions.

U.S. EPA. 1993. *Technical Support Document for Land Application of Sewage Sludge.* Volumes I and II. EPA 822/R-93-001a. Office of Water. Washington, D.C.

U.S. EPA (1995) recommended that bioconcentration factors for the metals cadmium, mercury, selenium, and zinc presented in this document be used to derive Ba_{beef} values. Following the method recommended by U.S. EPA (1992) for dioxins, the bioconcentration factors—with units of (kilograms feed DW/kilogram tissue DW—are divided by feed ingestion rates (kilogram feed DW/day]) to calculate Ba_{beef} values (day/kilogram tissue DW). A feed ingestion rate of 20 kg DW/day is recommended by U.S. EPA (1993).

U.S. EPA. 1994a. *Estimating Exposures to Dioxin-like Compounds. Volume III: Site-specific Assessment Procedures.* Office of Research and Development. EPA/600/6-88/005Cc. External Review Draft. June.

This document recommends an F_i value of 1; this value assumes that 100 percent of the plant materials ingested by cattle have been grown on soil contaminated by emissions.

U.S. EPA. 1994b. *Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Solid Waste and Emergency Response. EPA-530-R-94-021. April.

This document recommends an F_i value of 1; this value assumes that 100 percent of the plant materials ingested by cattle have been grown on soil contaminated by emissions.

U.S. EPA. 1994c. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document is one of the reference source documents for the equation in Table B-3-10. This document also recommends the following:

- An F_i value of 100 percent
- Qp_i values for forage, silage, and grain of 8.8, 2.5 and 0.47 kg dry weight/day, respectively, based on Boone, Ng, and Palms (1981), NAS (1987), McKone and Ryan (1989), and Rice (1994)
- A soil ingestion rate for cattle (θ_{sw}) of 0.5 kg/day, based on USDA (1994), Rice (1994), and NAS (1987)
- A range (1.1x 10^{-09} to 4.8 day/kg animal tissue) of Ba_{beef} values-based on Baes, Sharp, Sjoreen, and Shor (1984), McLachlan, Thoma, Reissinger, and Hutzinger (1990), and Travis and Arms (1988).

U.S. EPA. 1995a. *Further Issues for Modeling the Indirect Exposure Impacts from Combustor Emissions.* Office of Research and Development. Washington, D.C. January 20.

U.S. EPA (1995)a does not recommend using the Travis and Arms (1988) equation to calculate Ba_{beef} values for dioxin-like compounds. U.S. EPA (1995a) notes that cow milk experimental data derived by McLachlan (1990) was used in the U.S. EPA (1992) dioxin exposure document to calculate biotransfer factors with units of (kilogram feed/kilogram tissue). U.S. EPA (1995a) then divides these biotransfer factors by feed ingestion rates (kilogram feed/day) to calculate Ba_{milk} values for dioxin and furan compounds. U.S. EPA (1995a) then recommends that Ba_{beef} be extrapolated from these dioxin and furan Ba_{milk} values. The Ba_{milk} values are converted to Ba_{beef} by assuming the fat contents of beef and milk. U.S. EPA (1992) assumes that milk is 3.5 percent fat and that beef is 19 percent fat. Therefore, U.S. EPA (1995a) concludes that Ba_{beef} would be 5.4 times higher (19/3.5) than Ba_{milk}.

This document recommends using *BCF* for the metals cadmium, mercury, selenium, and zinc, presented in U.S. EPA (1993), to calculate Ba_{beef} values for these metals. Specifically, the *BCFs* from U.S. EPA (1993)—which are in units of kilogram feed DW/kilogram tissue DW are divided by a feed ingestion rate of 20 kilograms DW/day to arrive at Ba_{beef} values in units of day/kilogram tissue DW, according to the methodology developed for dioxins (U.S. EPA 1992).

U.S. EPA. 1995b. "Waste Technologies Industries Screening Human Health Risk Assessment (SHHRA): Evaluation of Potential Risk from Exposure to Routine Operating Emissions." Volume V. External Review Draft. U.S. EPA Region 5, Chicago, Illinois.

U.S. EPA. 1997a. *Exposure Factors Handbook.* "Food Ingestion Factors". Volume II. SAB Review Draft. EPA/600/P-95/002F. August.

U.S. EPA. 1997b. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

TABLE B-3-11

MILK CONCENTRATION DUE TO PLANT AND SOIL INGESTION (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Description

This equation first estimates the daily amount of COPCs taken in by cattle through the ingestion of contaminated plant and soil material. The equation then recommends the use of biotransfer factors to transform the daily animal intake of a COPC (mg COPC/day) into an animal (dairy cattle) milk COPC concentration (mg COPC/kg FW tissue).

The limitations and uncertainty introduced in calculating this variable include the following:

(1) Variables P_i and Cs are COPC- and site-specific. Uncertainties associated with these variables are site-specific.
(2) Uncertainties associated with the variables F_i, Qs, and Qp_i are expected to be minimal.
(3) Ba_{milk} values may not reflect site-specific conditions—Ba_{milk} values for nondioxin-like organics are based on a generalized regression equation; Ba_{milk} values for dioxins and furans are estimated on the basis of experimental values from a single lactating cow; and Ba_{milk} values for inorganics are based on integration of a wide variety of empirical and experimental result which can mean that site-specific difference are ignored.

Based on the information below, A_{milk} is dependent on the concentrations of COPCs estimated in plant feeds and soil, and the biotransfer factor estimated for each compound.

Equation

$$A_{milk} = \left(\sum (F_i \cdot Qp_i \cdot P_i) + Qs \cdot Cs \cdot Bs \right) \cdot Ba_{milk} \cdot MF$$

For mercury modeling, milk concentration due to plant and soil ingestion is calculated for divalent mercury (Hg^{2+}) and methyl mercury (MHg) using their respective P_i, Cs, and Ba_{milk} values.

Variable	Description	Units	Value
A_{milk}	Concentration of COPC in milk	mg COPC/kg FW tissue	
F_i	Fraction of plant type (*i*) grown on contaminated soil and ingested by the animal	unitless	**1.0** This variable is site- and plant type-specific. Plant types for cattle are identified as grain, forage, and silage. U.S. EPA OSW recommends that a default value of 1.0 be used for all plant types. This is consistent with U.S. EPA (1990), U.S. EPA (1994a), U.S. EPA (1994b) and NC DEHNR (1997), which recommend that 100 percent of the plant materials ingested by cattle be assumed to have been grown on soil contaminated by emissions. The following uncertainty is associated with this variable: (1) 100 percent of the plant materials eaten by cattle are assumed to be grown on soil contaminated by facility emissions. This may overestimate A_{milk}.

TABLE B-3-11

MILK CONCENTRATION DUE TO PLANT AND SOIL INGESTION
(CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Description	Units	Value
Qp_i	Quantity of plant type (*i*) ingested by the animal per day	kg DW plant/day	**Forage: 13.2** **Silage: 4.1** **Grain: 3.0** This variable is site- and plant type-specific; plant types for cattle are identified as grain, forage, and silage. U.S. EPA OSW recommends that cattle raised by subsistence milk farmers be evaluated by using the following values for *Qp*: forage (13.2), silage (4.1), and grain (3.0). The recommended plant type-specific Qp_i values were calculated as follows. First, total dry matter intake (DMI) was estimated as 20 kg DW/day, based on information presented in NAS (1987). Second, data from Boone, Ng, and Palms (1981) were used to separate the total DMI into plant type-specific fractions. Finally, the recommended plant type-specific Qp_i values were calculated by multiplying the estimated total DMI (20 kg DW/day) by the plant type-specific fractions. For example, the Qp_i for forage was calculated as 20 kg DW/day · 0.65 = 13.2 kg DW/day. These values are consistent with U.S. EPA (1990), U.S. EPA (1993), U.S. EPA (1994b), and U.S. EPA (1995), and NC DEHNR (1997). These reference documents cite Boone, Ng, and Palms (1981), NAS (1987), McKone and Ryan (1989), and Rice (1994) as primary references for plant ingestion rates. Although not typically recommended by U.S. EPA—because subsistence milk farmers rely on a higher percentage of forage and silage to feed cattle, whereas typical milk farmers rely on a greater amount of grain to feed cattle—it may be appropriate in site-specific cases to evaluate cattle raised by typical milk farmers by using the following values for *Qp*: forage (6.2), silage (1.9), and grain (12.2), as presented in Rice (1994). These values are also consistent with U.S. EPA (1990), U.S. EPA (1993), U.S. EPA (1994b), and NC DEHNR (1996). Uncertainties introduced by this variable include the following: (1) The plant type-specific Qp_i values were calculated based on a total DMI of 20 kg DW/day (NAS 1987) rather than the total DMI of 17 kg DW/day presented in Boone, Ng, and Palms (1981) and McKone and Ryan (1989). Site-specific total DMI values may vary. (2) The plant type-specific fractions calculated from Boone, Ng, and Palms (1981) may not accurately represent site-specific or local plant type-specific fractions.

Variable	Description	Units	Value
P_i	Concentration of COPC in plant type *(i)* ingested by the animal	mg/kg DW	**Varies** This variable is COPC-, site-, and plant type-specific; plant types for cattle are identified as grain, forage, and silage. Values for *Pd*, *Pv*, and *Pr* are calculated by using the equations in Tables B-3-7, B-3-8, and B-3-9; and then summed for each plant type to determine P_i. Uncertainties introduced by this variable include the following: (1) Some of the variables in the equations in Tables B-3-7, B-3-8, and B-3-9—including *Cs*, *Cyv*, *Q*, *Dydp*, and *Dywp*—are COPC- and site-specific. Uncertainties associated with these variables are site-specific. (2) In the equation in Table B-3-7, uncertainties associated with other variables include the following: F_w (values for organic compounds estimated on the basis of the behavior of polystyrene microspheres), *Rp* (estimated on the basis of a generalized empirical relationship), *kp* (estimation process does not consider chemical degradation), and *Yp* (estimated on the basis of national harvest yield and area planted values). All of these uncertainties contribute to the overall uncertainty associated with P_i. (3) In the equation in Table B-3-8, COPC-specific *Bv* values for nondioxin-like compounds may be overestimated by up to one order of magnitude, based on experimental conditions used to develop the algorithm to estimate *Bv* values. (4) In the equation in Table B-3-9, COPC-specific plant-soil biotransfer factors (*Br*) may not reflect site-specific conditions. This may be especially true for inorganic COPCs for which estimates of *Br* would be more accurately estimated by using plant uptake response slope factors.

MILK CONCENTRATION DUE TO PLANT AND SOIL INGESTION (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Description	Units	Value
Qs	Quantity of soil ingested by the animal	kg/day	**0.4** This variable is site-specific. U.S. EPA OSW recommends the 0.4 kg/day soil ingestion rate be used. This is consistent with NC DEHNR (1997) and U.S. EPA (1994b), which cite USDA (1994), Rice (1994), and NAS (1987). Briefly, the recommended *Qs* value was calculated as follows. First, a total DMI was estimated as 20 kg DW/day based on information presented in NAS (1987). Second, USDA (1994) estimates that *Qs* equals 2 percent of the total DMI. Finally, the recommended *Qs* value was calculated as 20 kg DW/day · 0.02 = 0.4 kg DW /day. Although not typically recommended by U.S. EPA—because subsistence milk farmers rely on a higher percentage forage to feed cattle, while typical milk farmers rely on greater amounts of grain to feed cattle—it may be appropriate in site-specific cases to evaluate cattle raised by typical milk farmers using a value for *Qs* of 0.25 kg/day. This is consistent with NC DEHNR (1997), which cites Rice (1994) as the source of this value. Uncertainties introduced by this variable include: (1) The recommended *Qs* value was based on a total DMI of 20 kg DW/day NAS (1987) rather than the total DMI of 17 kg DW/day presented in Boone, Ng, and Palms (1981) and McKone and Ryan (1989). To the extent that site-specific or local total DMI values may vary, A_{milk} may be under- or overestimated to a limited degree. (2) USDA (1994) states that *Qs* equals 2 percent of the total DMI for dairy cattle on a subsistence farm. Although the basis of the estimate of 2 percent is not known, it is apparent that to the extent that site-specific or local *Qs* values are different than 2 percent, A_{milk} may be under- or overestimated to some degree.
Cs	Average soil concentration over exposure duration	mg COPC/kg soil	**Varies** This variable is COPC- and site-specific, and should be calculated by using the equation in Table B-3-1. Uncertainties are site-specific.
Bs	Soil bioavailability factor	unitless	**1.0** The soil bioavailability factor, *Bs,* can be thought of as the ratio between bioconcentration (or biotransfer) factors for soil and vegetation for a given COPC. The efficiency of transfer from soil may differ from efficiency or transfer from plant material for some COPCs. If the transfer efficiency is lower for soils, than this ratio would be less than 1.0. If it is equal or greater than that of vegetation, the *Bs* would be equal to or greater than 1.0. Due to limited data regarding bioavailability from soil, U.S. EPA OSW recommends a default value of 1.0 for *Bs,* until more COPC-specific data is available for this parameter. Some COPCs may be much less bioavailable from soil than from plant tissues. This uncertainty may overestimate *Bs*.

Variable	Description	Units	Value
Ba_{milk}	Biotransfer factor for milk	day/kg FW tissue	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. Ba_{milk} is defined as the ratio of the COPC concentration in milk (mg COPC/kg tissue) to the daily intake of the COPC (mg COPC/day) by the animal. Uncertainties introduced by this variable include the following: (1) U.S. EPA OSW recommends that Ba_{milk} values for organic COPCs other than dioxins and furans be calculated by using the regression equation developed on the basis of a study of 29 organic compounds. Values calculated by using this regression equation may not accurately represent the behavior of organic COPCs under site-specific conditions. Therefore, estimates of Ba_{milk} and, therefore, A_{milk} may be under- or overestimated to some degree. (2) U.S. EPA OSW (1994c) recommends use of Ba_{milk} values for dioxins and furans developed by U.S. EPA (1995). These values were developed by using experimental data for a single cow from McLachlan, Thoma, Reissinger, and Hutzinger (1990). The uptake and distribution of dioxins and furans in this single animal may not accurately represent the behavior of these compounds in livestock under site-specific conditions. Therefore, Ba_{milk}, and A_{milk} value may be under- or overestimated to some degree. (3) U.S. EPA recommended that Ba_{milk} values for metals be calculated by using single COPC-specific uptake factors developed by Baes, Sharp, Sjoreen, and Shor (1984). These uptake factors may not accurately represent the behavior of inorganic COPCs under site-specific conditions; therefore, Ba_{milk} and, therefore, A_{milk} value may be under- or overestimated to some degree.
MF	Metabolism factor	unitless	**0.01 and 1.0** This variable is COPC-specific. Based on a study by Ikeda et al. (1980), U.S. EPA (1995a) recommended using a metabolism factor to account for metabolism in animals to offset the amount of bioaccumulation suggested by biotransfer factors. MF applies only to beef, milk, and pork. It does not apply to direct exposures to air, soil, or water, or to ingestion of produce, chicken, or fish. U.S. EPA (1995b) recommended an MF of 0.01 for bis(2-ethylhexyl)phthalate (BEHP) and 1.0 for all other COPCs.

REFERENCES AND DISCUSSION

Baes, C.F., R.D. Sharp, A.L. Sjoreen, and R.W. Shor. 1984. *Review and Analysis of Parameters and Assessing Transport of Environmentally Released Radionuclides through Agriculture.* Oak Ridge National Laboratory, Oak Ridge, Tennessee.

U.S. EPA (1994c) recommends Baes, Sharp, Sjoreen, and Shor (1984) as a source of (1) Ba_{milk} values for inorganics, and (2) water content of 0.9 for cow's milk, which can be used to convert Ba_{milk} values in dry weight to wet weight.

Belcher, G.D., and C.C. Travis. 1989. *Modeling Support for the RURA and Municipal Waste Combustion Project Final Report on Sensitivity and Uncertainty Analysis for the Terrestrial Food Chain Model.* Prepared under IAG-1824-A020-A1 by Oak Ridge National Laboratory for U.S. EPA Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office. Cincinnati, Ohio.

This document was cited by U.S. EPA (1990) as the source of Ba_{milk} values for cadmium.

Boone, F.W., Yook C. Ng, and John M. Palms. 1981. "Terrestrial Pathways of Radionuclide Particulates." *Health Physics.* Vol. 41, No. 5, pages 735-747. November.

This document is identified as a source of plant ingestion rates. Boone, Ng, and Palms (1981) reports a total forage, grain, and silage ingestion rate of 17 kg DW/day for subsistence dairy cattle. Also, this document states that this total DMI of 17 kg DW/day is made up of the following plant type-specific fractions: forage (65 percent), grain (15 percent), and silage (20 percent).

USDA. 1994. Personal Communication Regarding Soil Ingestion Rate for Dairy Cattle. Between G.F. Fries, Agricultural Research Service, and Glenn Rice and Jennifer Windholtz, U.S. EPA, Office of Research and Development. March 22.

NC DEHNR (1997) and EPA (1994c) note that USDA (1994) reports soil ingestion to be 2 percent of the total DMI for dairy cattle on subsistence farms.

Ikeda, G.J., P.P. Sapenza, and J.L. Couvillion. 1980. "Comparative distribution, excretion, and metabolism of di(2-ethylhexyl)phthalate in rats, dogs, and pigs." *Food Cosmet. Toxicology.* 18:637- 642.

McKone, T.E., and P.B. Ryan. 1989. *Human Exposures to Chemicals Through Food Chains: An Uncertainty Analysis.* Livermore, California: Lawrence Livermore National Laboratory Report. UCRL-99290.

This document is cited as a source of plant ingestion rates. According to EPA (1990), McKone and Ryan (1989) report an average total subsistence ingestion rate of 17 kg dry weight/day for the three plant feeds, which is consistent with the total recommended by Boone, Ng, and Palms (1981) for subsistence cattle.

McLachlan, M.S., H. Thoma, M. Reissinger, and O. Hutzinger. 1990. " PCDD/F in an Agricultural Food Chain, Part 1: PCDD/F Mass Balance of a Lactating Cow." *Chemosphere*, Vol. 20, Nos. 7-9, pp. 1013-1020.

This document is identified as a source of cow milk experimental data used in the U.S. EPA (1992) dioxin document to calculate bioconcentration factors with units of (kg feed/kg milk). This study inventoried the dioxins and furans ingested by a single lactating cow, and the dioxins and furans emitted through the milk. The volume of milk generated by the cow was also given.

NAS. 1987. *Predicting Feed Intake of Food-Producing Animals.* National Research Council, Committee on Animal Nutrition. Washington, D.C.

NC DEHNR (1997) and U.S. EPA (1994c) note that this document reports a daily DMI equal to 3.2 percent of an average dairy cattle body weight of 630 kilograms; this results in a daily DMI of 630 kg DW · 0.032 = 20.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

Grains such as corn may be grown specifically as cattle feed. COPC uptake into these feed materials may occur through root uptake, wet and dry deposition of particulate-bound COPCs on plants, and vapor-phase uptake of COPCs through plant foliage. Plants are classified as "protected" if they have an outer covering that acts as a barrier to direct deposition and vapor uptake of air contaminants. NC DEHNR (1997) classifies grains as protected, and recommends that only root uptake of COPCs be evaluated for grains. Because silage may consist of forage materials that have been stored and fermented, it should be treated as forage (that is, as unprotected).

This document is a reference source for the equation in Table B-3-11. This document also recommends the following:

(1) An F_i value of 1
(2) Forage, silage, and grain ingestion rates (Qp_i) of 13.2, 4.1, and 3.0 kg DW/day for subsistence dairy farmer cattle, respectively, based on a total DMI of 20 kg DW/day calculated from NAS (1987) and plant type-specific fractions from Boone, Ng, and Palms (1981)
(3) Forage, silage, and grain ingestion rates (Qp_i) of 6.2, 1.9, and 12.2 kg DW/day, respectively for typical dairy farmer cattle based on USDA (1994)
(4) A Qs value of 0.4 kg/day, based on NAS (1987) and USDA (1994)
(5) Ba_{milk} values ranging from 3.5 x 10^{-10} to 4.8, based on Baes, Sharp, Sjoreen, and Shor (1984) and Travis and Arms (1988).

NC DEHNR (1997) recommends forage, grain, and silage ingestion rates of 3.8, 3.8, and 1.0 kg dry/day, respectively, for typical farmer milk cattle.

Travis, C.C., and A.D. Arms. 1988. "Bioconcentration of Organics in Milk, and Vegetation". *Environmental Science and Technology.* 22:271-274

For organic COPCs, NC DEHNR (1997), U.S. EPA (1990), and U.S. EPA (1994c) recommend that the regression equation from Travis and Arms (1988) be used to calculate biotransfer factors for milk (Ba_{milk}). Travis and Arms (1988) reports a positive correlation between log K_{ow} and Ba_{milk} values and recommends using log K_{ow} to calculate Ba_{milk} values for organic compounds. Specifically, the following regression equation is recommended:

$$\log Ba_{milk} = -8.1 + \log K_{ow}$$

where

Ba_{milk}	=	Biotransfer factor for milk (day/kg FW tissue)
K_{ow}	=	Octanol-water partition coefficient (unitless) (see Appendix A-3)

U.S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA/600/6-90/003. January.

This document is a reference source for the equation in Table B-3-10. This document also recommends the following:

(1) An F_i value of 1
(2) Forage, silage, and grain ingestion rates (Qp_i) of 11.0, 3.3, and 2.6 kg DW/day; these are reported as average ingestion rates and are based on a total DMI of 17 kg DW/day, as reported in Boone, Ng, and Palms (1981), and McKone and Ryan (1989)
(3) Ba_{milk} values for organics, calculated by using the regression equation developed by Travis and Arms (1988), and a Ba_{milk} value for cadmium from Belcher and Travis (1989).

U.S. EPA. 1992. *Technical Support Document for Land Application of Sewage Sludge.* Volumes I and II. EPA 822/R-93-001a. Office of Water. Washington, D.C.

U.S. EPA (1995) recommends that bioconcentration factors for the metals cadmium, mercury, selenium, and zinc, cited by U.S. EPA (1993), be used to derive Ba_{milk} values. Following the method recommended by U.S. EPA (1992) for dioxins, the bioconcentration factors, with units of (kg feed DW/kg tissue DW), are divided by feed ingestion rates (kg feed DW/day) to calculate Ba_{milk} values (day/kg FW tissue). A feed ingestion rate of 20 kg DW/day is recommended by U.S. EPA (1993). It is likely that the feed ingestion rate from U.S. EPA (1993) is based on NAS (1987).

U.S. EPA. 1994a. *Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Solid Waste and Emergency Response. EPA-530-R-94-021. April.

This document recommends a F_i value of 1, assuming that 100 percent of the plant materials ingested by cattle have been grown on soil contaminated by combustion unit emissions.

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document is a reference source for the equation in Table B-3-11. This document also recommends the following:

(1) An F_i value of 1
(2) A forage ingestion rate (Qp_i) value of 13.2 kg DW/day, from NAS (1987) and Boone, Ng, and Palms (1981)
(3) A quantity of soil ingested (Qs) value of 0.4 kg/day, based on NAS (1987) and USDA (1994)
(4) Ba_{milk} values ranging from 3.5×10^{-10} to 4.8, based on Baes, Sharp, Sjoreen, and Shor (1984), and Travis and Arms (1988)

U.S. EPA. 1994c. *Estimating Exposures to Dioxin-Like Compounds. Volume III: Site-specific Assessment Procedures.* External Review Draft. Office of Research and Development. EPA/600/6-88/005Cc. June.

This document reported bioconcentration factors for dioxin-like compounds (dioxin and furan congeners) calculated on the basis of experimental data derived by McLachlan, Thoma, Reissinger, and Hutzinger (1990).

U.S. EPA. 1995a. *Further Issues for Modeling the Indirect Exposure Impacts from Combustor Emissions.* Office of Research and Development. Washington, D.C. January.

U.S. EPA (1995a) does not recommend using the Travis and Arms (1988) equations to calculate Ba_{milk} values for dioxin-like compounds. U.S. EPA (1995a) notes that cow milk experimental data derived by McLachlan (1990) was used in the U.S. EPA (1992) dioxin exposure document to calculate biotransfer factors with units of [kg feed/kg tissue]. U.S. EPA (1995a) then divides these biotransfer factors by feed ingestion rates (kg feed/day) to calculate Ba_{milk} values for dioxin and furan compounds.

U.S. EPA. 1995b. "Waste Technologies Industries Screening Human Health Risk Assessment (SHHRA): Evaluation of Potential Risk from Exposure to Routine Operating Emissions." Volume V. External Review Draft. U.S. EPA Region 5, Chicago, Illinois.

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

PORK CONCENTRATION DUE TO PLANT AND SOIL INGESTION (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Description

This equation first estimates the daily intake of COPCs through the ingestion of contaminated plant and soil material. The equation then recommends the use of biotransfer factors to transform the daily animal intake of a COPC (mg COPC/day) into an animal COPC tissue concentration (mg COPC/kg tissue).

The limitations and uncertainty introduced in calculating this variable include the following:

(1) Uncertainties associated with the variables P_i and Cs are COPC- and site-specific.
(2) Uncertainties associated with the variables F_i, Q, and Qp_i are expected to be minimal.
(3) Uncertainties associated with Ba_{pork} values may be significant for two primary reasons: (a) Ba_{pork} for dioxins are calculated from Ba_{milk} values that are based on metabolism of dioxins rather than a sow, and (b) the source or methodology used to calculate the Ba_{pork} values for organics other than dioxins and inorganics other than cadmium, mercury, selenium, and zinc as reported in NC DEHNR (1997) is not known. Therefore, the magnitude and direction of the associated uncertainties cannot be specified.

Based on the information below, A_{pork} is dependent on the concentrations of COPCs estimated in plant feeds and soil, and the biotransfer factor estimated for each COPC.

Equation

$$A_{pork} = \left(\sum (F_i \cdot Qp_i \cdot P_i) + Qs \cdot Cs \cdot Bs \right) \cdot Ba_{pork} \cdot MF$$

For mercury modeling, pork concentration due to plant and soil ingestion is calculated for divalent mercury (Hg^{2+}) and methyl mercury (MHg) using their respective P_i, Cs, and Ba_{pork} values.

Variable	Description	Units	Value
A_{pork}	Concentration of COPC in pork	mg COPC/kg FW tissue	
F_i	Fraction of plant type *(i)* grown on contaminated soil and ingested by the animal	unitless	**1.0** This variable is site- and plant type-specific; plant types for swine are typically identified as grain and silage. U.S. EPA OSW recommends that a default value of 1.0 be used for all plant types. This is consistent with U.S. EPA (1990), U.S. EPA (1994a), U.S. EPA (1994c), and NC DEHNR (1996), which recommend that 100 percent of the plant materials ingested by swine be assumed to have been grown on soil contaminated by emissions. The following uncertainty is associated with this variable: (1) 100 percent of the plant materials ingested by cattle are assumed to be grown on soil contaminated by facility emissions. This may overestimate A_{pork}.

Variable	Description	Units	Value
Qp_i	Quantity of plant type (*i*) ingested by the animal each day	kg DW plant/day	**Silage: 1.4** **Grain: 3.3** This variable is site- and plant type-specific; plant types for swine are typically identified as grain and silage. U.S. EPA OSW recommends that swine raised by subsistence farmers be evaluated by using the following values for *Qp*: silage (1.4) and grain (3.3). These Qp_i values are based on a total DMI value of 4.7 kg DW/day, and plant type-specific diet fractions (70 percent grain and 30 percent silage) are based on U.S. EPA (1982). NC DEHNR (1997) and U.S. EPA (1990) recommend silage and grain ingestion rates of 1.3 and 3.0 kg dry/day, respectively, for swine. NC DEHNR (1997) references U.S. EPA (1990) as the source of these ingestion rates. The difference between the default Qp_i values and values recommended by NC DEHNR (1997) and U.S. EPA (1990) is the total DMI upon which they are based. Specifically, U.S. EPA OSW recommends the use of a total DMI for swine of 4.7 kg DW/day, based on U.S. EPA (1995), whereas NC DEHNR (1997) and U.S. EPA (1990) recommend a total DMI of 4.3 kg dry weight/day. NC DEHNR (1997) and U.S. EPA (1990) do not differentiate between subsistence and typical hog farmers as they do for cattle, because it is assumed that forage is not a significant portion of a hog's diet. Uncertainties introduced by this variable include the following: (1) The recommended grain and silage ingestion rates may not accurately represent site-specific or local conditions. Therefore, Qp_i and A_{pork} values may be under- or overestimated to some degree.

TABLE B-3-12

PORK CONCENTRATION DUE TO PLANT AND SOIL INGESTION
(CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Description	Units	Value
P_i	Concentration of COPC in plant type (*i*) ingested by the animal	mg/kg DW	**Varies** This variable is COPC-, site-, and plant type-specific; plant types for swine are identified as grain and silage. Values for *Pd*, *Pv*, and *Pr* are calculated by using the equations in Tables B-3-7, B-3-8, and B-3-9; and then summed for each plant type to determin P_i. Uncertainties introduced by this variable include the following: (1) Some of the variables in the equations in Tables B-3-7, B-3-8, and B-3-9—including *Cs, Cyv, Q, Dydp*, and *Dywp*—are COPC- and site-specific. Uncertainties associated with these variables are site-specific. (2) In the equation in Table B-3-7, uncertainties associated with other variables include: F_w (values for organic compounds based on behavior of polystyrene microspheres), *Rp* (estimated on the basis of a generalized empirical relationship), *kp* (estimation process does not consider chemical degradation) and *Yp* (estimated based on national harvest yield and area planted values). All of these uncertainties contribute to the overall uncertainty associated with P_i. (3) In the equation in Table B-3-8, COPC-specific *Bv* values for nondioxin-like compounds may be overestimated by up to one order of magnitude, based on experimental conditions used to develop the algorithm to estimate *Bv* values. (4) In the equation in Table B-3-9, COPC-specific soil-to-plant biotransfer factors (*Br*) may not reflect site-specific conditions. This may be especially true for inorganic COPCs for which estimates of *Br* would be accurately estimated by using plant uptake response slope factors.
Qs	Quantity of soil ingested by the animal	kg/day	**0.37** This variable is site-specific. U.S. EPA OSW recommends that the soil ingestion rate 0.37 kg/day be used. U.S. EPA (1990) states that sufficient data are not available to estimate swine soil ingestion rates. NC DEHNR (1997) recommends a soil ingestion rate for swine of 0.37 kg/day. This is estimated by assuming a soil intake of 8 percent of the total DMI. NC DEHNR (1997) does not specify the total DMI used to estimate *Qs*. However, mathematically, *Qs* appears to be based on a total DMI of 4.7 kg DW/day ($4.7 \cdot 0.08 = 0.37$), which is consistent with U.S. EPA (1995). The following uncertainty is associated with this variable: (1) The recommended soil ingestion rate may not accurately represent site-specific or local conditions. Therefore, *Qs* and A_{pork} values, may be under- or overestimated to some degree.
Cs	Average soil concentration over exposure duration	mg COPC/kg soil	**Varies** This variable is COPC- and site-specific, and should be calculated by using the equation in Table B-3-1. Uncertainties are site-specific.

TABLE B-3-12

PORK CONCENTRATION DUE TO PLANT AND SOIL INGESTION (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Description	Units	Value
Bs	Soil bioavailability factor	unitless	**1.0** The soil bioavailability factor, *Bs,* can be thought of as the ratio between bioconcentration (or biotransfer) factors for soil and vegetation for a given COPC. The efficiency of transfer from soil may differ from efficiency or transfer from plant material for some COPCs. If the transfer efficiency is lower for soils, than this ratio would be less than 1.0. If it is equal or greater than that of vegetation, the *Bs* would be equal to or greater than 1.0. Due to limited data regarding bioavailability from soil, U.S. EPA OSW recommends a default value of 1.0 for *Bs,* until more COPC-specific data is available for this parameter. Some COPCs may be much less bioavailable from soil than from plant tissues. This uncertainty may overestimate *Bs.*
Ba_{pork}	Biotransfer factor for pork	day/kg FW tissue	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. Ba_{pork} is defined as the ratio of the COPC concentration in animal tissue (mg COPC/kg FW tissue) to the daily intake of the COPC (mg COPC/day) by the animal. Uncertainties introduced by this variable include the following: (1) U.S. EPA OSW recommends that Ba_{pork} values for organic COPCs other than dioxins and furans be calculated by using the regression equation developed on the basis of a study of 29 organic compounds. Values calculated by using this regression equation may not accurately represent the behavior of organic COPCs under site-specific conditions. Therefore, estimates of Ba_{pork} and, therefore, A_{pork} may be under- or overestimated to some degree. (2) U.S. EPA OSW recommends use of Ba_{pork} values for dioxins and furans developed by U.S. EPA (1995). These values were developed by using experimental data for a single cow from McLachlan, Thoma, Reissinger, and Hutzinger (1990). The uptake and distribution of dioxins and furans in this single animal may not accurately represent the behavior of these compounds in livestock under site-specific conditions. Also, using the pork-to-milk fat content ratio to estimate Ba_{pork} values from Ba_{milk} values assumes that (1) COPCs bioconcentrate in the fat tissues, and (2) there are no differences in metabolism or feeding characteristics between beef cattle and pigs. Due to uncertainties associated with these assumptions, Ba_{pork}, and A_{pork} values may be under- or overestimated to some degree. (3) The sources or methodology used to support or estimate Ba_{pork} values presented in NC DEHNR (1997) are not known. Therefore, the degree to which these values represent the behavior of COPCs under site-specific conditions cannot be determined.

TABLE B-3-12

PORK CONCENTRATION DUE TO PLANT AND SOIL INGESTION (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Description	Units	Value
MF	Metabolism factor	unitless	**0.01 and 1.0** This variable is COPC-specific. Based on a study by Ikeda et al. (1980), U.S. EPA (1995a) recommended using a metabolism factor to account for metabolism in animals to offset the amount of bioaccumulation suggested by biotransfer factors. MF applies only to beef, milk, and pork. It does not apply to direct exposures to air, soil, or water, or to ingestion of produce, chicken, or fish. U.S. EPA (1995b) recommends an MF of 0.01 for bis(2-ethylhexyl)phthalate (BEHP) and 1.0 for all other COPCs.

REFERENCES AND DISCUSSION

Boone, F.W., Yook C. Ng, and John M. Palms. 1981. "Terrestrial Pathways of Radionuclide Particulates." *Health Physics*, Vol. 41, No. 5, pp. 735-747. November.

This document is cited as the source of a total DMI for hogs of 3.4 kg DW/day.

Ikeda, G.J., P.P. Sapenza, and J.L. Couvillion. 1980. "Comparative distribution, excretion, and metabolism of di(2-ethylhexyl)phthalate in rats, dogs, and pigs." *Food Cosmet. Toxicology.* 18:637- 642.

McLachlan, M.S., H. Thoma, M. Reissinger, and O. Hutzinger. 1990. "PCDD/F In An Agricultural Food Chain, Part 1: PCDD/F Mass Balance of a Lactating Cow." *Chemosphere*, Vol. 20, Nos. 7-9, pp. 1013-1020.

This document presents cow milk experimental data used in U.S. EPA (1994b) to calculate biotransfer factors relating concentrations of dioxins and furans in feed to concentrations of dioxins and furans in cow milk. Specifically, this study inventoried the dioxins and furans ingested by a single lactating cow, the dioxins and furans emitted through the milk, and the volume of milk generated by the cow.

U.S. EPA (1995) cited this study as a credible basis for calculating Ba_{beef} values from Ba_{milk} values based on the ratio of fat content in beef versus milk. NC DEHNR (1997) suggests that this same methodology can be used to calculate Ba_{pork} values for dioxins and furans.

NAS. 1987. *Predicting Feed Intake of Food-Producing Animals.* National Research Council, Committee on Animal Nutrition, Washington, D.C.

This document presents a total DMI for lactating sows of 5.2 kg DW/day. This document is also cited by U.S. EPA (1995) as the source of a total DMI for swine of 4.7 kg DW/day. As presented in this document, the value of 4.7 kg DW/day represents the average of specific total DMI values for gilts (young sows) and for lactating sows.

Ng, Y.C., C.S. Colsher, and S.E. Thomson. 1982. *Transfer Coefficients for Assessing the Dose from Radionuclides in Meat and Eggs.* U.S. Nuclear Regulatory Commission. Final Report. NUREG/CR-2976.

This document is cited as the source of biotransfer factors (Ba_{pork}) for several inorganic COPCs. However, U.S. EPA (1995) notes that "a large degree of uncertainty" exists in many of the experiments used in this document to develop the biotransfer factors. The biotransfer factors developed by Ng, Colsher, and Thompson (1982) are not recommended for use by U.S. EPA .

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

Grains such as corn may be grown specifically as swine feed. COPC uptake into these feed materials may occur through root uptake, wet and dry deposition of particulate-bound constituents on plants, and vapor-phase uptake of COPCs through plant foliage. Plants are classified as "protected" if they have an outer covering that acts as a barrier to direct deposition and vapor uptake of air contaminants. NC DEHNR (1997) classifies grains as protected, and recommends that only root uptake of COPCs be evaluated for grains; because silage may consist of forage materials that have been stored and fermented, it should be treated as forage (that is, as unprotected).

This document also recommends the following:

- An F_i value of 1, assuming that 100 percent of the plant material eaten by swine have been grown on soil contaminated by combustion unit emissions.
- Plant type-specific Qp_i values for hogs of 3.0 and 1.3 kg DW/day for grain and silage, respectively. This document cites U.S. EPA (1990) as the source of these ingestion rates.
- A quantity of soil ingested (Qs) value of 0.37 kg DW/day. This value is calculated as 8 percent of the total DMI (U.S. EPA 1993a). The total DMI of 4.3 kg DW/day comes from U.S. EPA (1990).
- A range of Ba_{pork} values (1.3×10^{-09} to 5.8 day/kg wet tissue); however, the sources of or methodology used to estimate, these values are not identified.
- Ba_{pork} values for dioxins and furans may be estimated from Ba_{milk} values (derived from a study of a single lactating sow, McLachlan, Thoma, Reissinger, Hutzinger 1990) based on the ratio of fat content (23 percent) of pork (Pennington 1993) and the fat content (3.5 percent) of milk (U.S. EPA 1994b). This methodology is consistent with the approach recommended by U.S. EPA (1995) for calculating Ba_{beef} values from Ba_{milk} values.
- The source or methodology used to estimate Ba_{pork} values for organics other than dioxins is not identified. However, the following correlation equation correlating Ba_{pork} values with COPC-specific K_{ow} values can be back-calculated from the COPC-specific Ba_{pork} values presented in the document:

$$\log Ba_{pork} = -7.523 + \log K_{ow}$$

Pennington, J.A.T. 1989. *Food Values of Portions Commonly Used.* 15th ed. Harper and Row. New York.

Cited by NC DEHNR (1997)—actually NC DEHNR (1997) cities "Pennington (1993)" but presents only this document (Pennington 1989) in the reference section—for the estimated fat content of pork, 23 percent.

U.S. EPA. 1982. "Pesticides Assessment Guidelines Subdivision O." Residue Chemistry. Office of Pesticides and Toxic Substances, Washington, D.C. EPA/540/9-82-023.

This document is cited by U.S. EPA (1990) as the source of the assumption that 70 percent of the total DMI for swine is grain and 30 percent is silage.

U.S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA-600-90-003. January.

This document represents total dry matter intake (DMI) rates for hogs and lactating sows of 3.4 and 5.2 kg DW/day, respectively, and recommends the average of these two rates (4.3 kg DW/day) as the total DMI. U.S. EPA (1990) cites Boone, Ng, and Palms (1981) as the source of the hog ingestion rate and NAS (1987) as the source of the lactating sow ingestion rate.

This document then assumes that 70 percent of the total DMI for swine is grain and 30 percent is silage; fractions then are used to arrive at the recommended grain ingestion rate of 3.0 kg DW/day (4.3 kg DW/day · 0.70) and the recommended silage ingestion rate of 1.3 kg DW/day (4.3 kg DW/day · 0.30). U.S. EPA (1990) cites U.S. EPA (1982) as the source of the grain and silage fractions.

This document also recommends an F_i value of 1. This assumes that 100 percent of the plant material eaten by swine is grown on soil contaminated by combustion unit emissions.

U.S. EPA. 1992. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, D.C. November.

This document recommends that the quantity of soil (Qs) eaten by swine be estimated as 8 percent of the total DMI. This document states "Fries of USDA notes pigs exhibit 'rooting' behavior and assumes a maximum soil ingestion intake of 8 percent of dry matter based on a 2 to 8 percent range noted in his earlier PCB work." However, this document provides no citations of work performed by Fries or personal communications with Fries.

U.S. EPA. 1994a. *Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Solid Waste and Emergency Response. EPA-530-R-94-021. April.

This document recommends an F_i value of 1. This assumes that 100 percent of the plant material ingested by swine has been grown on soil contaminated by combustion unit emissions.

U.S. EPA. 1994b. *Estimating Exposure to Dioxin-Like Compounds. Volume III: Site-Specific Assessment Procedures.* External Review Draft. Office of Research and Development. Washington, D.C. EPA/600/6-88/005Cc. June.

This document states that milk is 3.5 percent fat. This document also uses experimental data derived by McLachlon, Thoma, Reissinger, and Hutzinger (1990) to calculate biotransfer factors with units of (kg feed/kg tissue).

U.S. EPA. 1994c. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document recommends an F_i value of 1. This assumes that 100 percent of the plant material eaten by swine has been grown on soil contaminated by combustion unit emissions.

U.S. EPA. 1995a. *Further Issues for Modeling the Indirect Exposure Impacts from Combustor Emissions.* Office of Research and Development. Washington, D.C. January 20.

This document calculates Ba_{pork} values for cadmium, mercury, selenium, and zinc by dividing uptake slope factors ([mg COPC/kg tissue DW]/[mg COPC/kg feed DW]) from U.S. EPA (1993b) - 0.003 (cadmium), 0.0234 (mercury), 2.94 (selenium), and 0.002 (zinc)—by a daily feed ingestion rate for pork of 4.7 kg DW/day (NAS 1987). This approach is similar to that recommended by U.S. EPA (1994b) for dioxins. The calculated biotransfer factors are 6.0×10^{-04} (cadmium); 0.0051 (mercury); 6.255×10^{-01} (selenium); and 4.0×10^{-04} (zinc).

This document also recommends that Ba_{beef} values for dioxins and furans be extrapolated from Ba_{milk} values for dioxins and furans. Specifically, Ba_{milk} values are multiplied by the ratio of the fat content (19 percent) for beef and the fat content (3.5 percent) of milk. NC DEHNR (1997) states that Ba_{pork} values for dioxins and furans can be calculated in a similar manner.

U.S. EPA. 1995b. "Waste Technologies Industries Screening Human Health Risk Assessment (SHHRA): Evaluation of Potential Risk from Exposure to Routine Operating Emissions." Volume V. External Review Draft. U.S. EPA Region 5, Chicago, Illinois.

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/$-97-005. December.

TABLE B-3-13

COPC CONCENTRATION IN EGGS
(CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Description

This equation calculates the COPC concentration in eggs due to ingestion of contaminated soil and grain by free-range chickens.

Uncertainties associated with this equation include the following:

(1) This pathway has typically been applied only to PCDDs and PCDFs. However, concentrations in chicken eggs for other organics and metals can be calculated using biotransfer factors in a similar approach as was used to calculate concentrations in animal tissue.

(2) The assumption that 10 percent of a chicken's diet is soil may not represent site-specific conditions. Stephens, Petreas, and Hayward (1995) suggest that the percentage of soil in the diet of chickens raised under field conditions may be greater than 10 percent. Therefore, the concentration of COPCs in eggs, A_{egg}, may be underestimated.

(3) Estimated COPC-specific soil-to-plant biotransfer factors (*Br*) may not reflect site-specific or local conditions. Therefore, estimates of *Pr* and A_{egg} may be under- or overestimated to some degree.

(4) The recommended *BCFs* used in calculation of Ba_{egg} may not accurately represent the behavior of COPCs under site-specific and local conditions. For example, Stephens, Petreas, and Hayward (1995) note that chickens raised under field conditions and probably had a higher than 10 percent soil in their diet, showed larger apparent *BCFs*. Therefore, the recommended *BCFs* may underestimate the concentration of COPCs in eggs, A_{egg}.

(5) The recommended *BCFs* are based on incomplete experimental results. Stephens, Petreas, and Hayward (1995) present complete experimental results. This study includes results from a high-dose group and a low-dose group; results are based on the full exposure period. A brief comparison of the results from Stephens, Petreas, and Hayward (1992) with those from Stephens, Petreas, and Hayward (1995) indicates that *BCFs* from the high-dose group are generally higher than *BCFs* from the low-dose group. Therefore, use of the currently recommended *BCFs* may underestimate the COPC concentration in eggs, A_{egg}.

Equation

$$A_{egg} = \left(\sum (F_i \cdot Qp_i \cdot P_i) + Qs \cdot Cs \cdot Bs \right) \cdot Ba_{egg}$$

For mercury modeling, the concentration of COPC in eggs is calculated for divalent mercury (Hg^{2+}) and methyl mercury (MHg) using their respective P_i, *Cs*, and Ba_{eggs} values.

Variable	Description	Units	Value
A_{egg}	Concentration of COPC in eggs	mg COPC/kg FW tissue	

TABLE B-3-13

COPC CONCENTRATION IN EGGS
(CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Description	Units	Value
F_i	Fraction of plant type *i* (grain) grown on contaminated soil and ingested by the animal	unitless	**1.0** This variable is site- and plant type-specific. F_i for chickens is estimated for grain feed only. U.S. EPA OSW recommends that a default value of 1.0 be used for all plant types. This is consistent with U.S. EPA (1990), U.S. EPA (1994a), U.S. EPA (1994b) and NC DEHNR (1997), which recommend that 100 percent of the plant materials ingested be assumed to have been grown on soil contaminated by facility emissions. The following uncertainty is associated with this variable: (1) 100 percent of the plant materials eaten by chickens are assumed to be grown on soil contaminated by facility emissions. This may overestimate A_{egg}.
Qp_i	Quantity of plant type *i* (grain) ingested by the animal	kg DW plant/day	**0.2** Qp_i for chicken is estimated for grain feed only, as recommended by NC DEHNR (1997) and U.S. EPA (1990). Uncertainties associated with this variable include the following: (1) Actual grain ingestion rates can vary from site to site; this can over- or underestimate Qp_i.
P_i	Concentration of COPC in plant type *I* (grain)	mg COPC/kg DW	**Varies** This variable is COPC-, site-, and plant type-specific. Values for *Pi* are calculated for grain by using the equations in Table B-3-9. Uncertainties introduced by this variable include the following: (1) Some of the variables in the equation in Table B-3-9—including *Cs, Cyv, Q, Dydp*, and *Dywp*—are COPC- and site-specific. Uncertainties associated with these variables are site-specific. (2) In the equation in Table B-3-9, COPC-specific plant-soil biotransfer factors (*Br*) may not reflect site-specific conditions. This may be especially true for inorganic COPCs for which estimates of *Br* would be more accurately estimated by using plant uptake response slope factors.
Qs	Quantity of soil ingested by the animal	kg/day	**0.022** This variable is site-specific. U.S. EPA OSW recommends that the soil ingestion rate of 0.022 kg/day be used. This is consistent with Stephens, Petreas, and Hayward (1995). Uncertainties introduced by this variable include the following: (1) The recommended soil ingestion rate may not accurately represent site-specific or local conditions. (2) Empirical data to support soil ingestion rates of chickens are limited.

TABLE B-3-13

COPC CONCENTRATION IN EGGS
(CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Description	Units	Value
Cs	Average soil concentration over exposure duration	mg COPC/kg soil	**Varies** This variable is COPC- and site-specific, and should be calculated by using the equation in Table B-3-1. Uncertainties are site-specific.
Bs	Soil bioavailability factor	unitless	**1.0** The soil bioavailability factor, *Bs,* can be thought of as the ratio between bioconcentration (or biotransfer) factors for soil and vegetation for a given COPC. The efficiency of transfer from soil may differ from efficiency or transfer from plant material for some COPCs. If the transfer efficiency is lower for soils, than this ratio would be less than 1.0. If it is equal or greater than that of vegetation, the *Bs* would be equal to or greater than 1.0. Due to limited data regarding bioavailability from soil, U.S. EPA OSW recommends a default value of 1.0 for *Bs,* until more COPC-specific data is available for this parameter. Some COPCs may be much less bioavailable from soil than from plant tissues. This uncertainty may overestimate *Bs*.
Ba_{egg}	Biotransfer factor for chicken eggs	day/kg FW tissue	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainties are associated with this variable: (1) U.S. EPA OSW recommends that Ba_{egg} values for organic COPCs other than dioxins and furans be calculated by using the regression equation developed on the basis of a study of 29 organic compounds. Values calculated by using this regression equation may not accurately represent the behavior of organic COPCs under site-specific conditions. Therefore, estimates of Ba_{egg} and, therefore, A_{egg} may be under- or overestimated to some degree. (2) The recommended *BCFs* may not accurately represent the behavior of COPCs under site-specific or local conditions. For example, Stephens, Petreas, and Hayward (1995) note that chickens raised under field conditions, and which probably had a more than 10 percent soil in their diet, showed larger apparent *BCFs*. Therefore, the recommended *BCFs* may underestimate the concentration of COPCs in eggs, A_{egg}. (3) The recommended *BCFs* are based on incomplete experimental results. Stephens, Petreas, and Hayward (1995) include results from a high-dose group and as a low-dose group; results are based on the full exposure period. A brief comparison of the results from Stephens, Petreas, and Hayward (1992) and those from Stephens, Petreas, and Hayward (1995) indicates that *BCFs* from the high-dose group are generally higher than *BCFs* from the low-dose group. Therefore, use of the currently recommended *BCFs* may underestimate the COPC concentration in eggs, A_{egg}.

REFERENCES AND DISCUSSION

California Environmental Protection Agency (CEPA). 1993. " Parameter Values and Ranges for CALTOX." Draft. Office of Scientific Affairs. California Department of Toxics Substances Control. Sacramento, CA. July.

Chang, R.R., D. Hayward, L. Goldman, M. Harnly, J. Flattery, and R.D. Stephens. 1989. "Foraging Farm Animals as Biomonitors for Dioxin Contamination." *Chemosphere.* Volume 19: 481-486.

This document appears to be cited by Stephens, Petreas, and Hayward (1992) as support for the assumption that soil represents 10 percent of the diet of free-range chickens.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is a reference source for the equation in Table B-3-13. This document also cites Stephens, Petreas, and Hayward (1992) as the source of estimates of the fraction of diet that is soil (*Fd*), and BCF_{egg} for dioxins and furans.

Petreas, M.X., L.R. Goldman, D.G. Hayward, R. Chang, J. Flattery, T. Wiesmuller, R.D. Stephens, D.M. Fry, and C. Rappe. 1991. "Biotransfer and Bioaccumulation of PCDD/PCDFs from Soils: Controlled Exposure Studies of Chickens." *Chemosphere.* Volume 23: 1731-1741.

This document appears to be cited by Stephens, Petreas, and Hayward (1992) and Stephens, Petreas, and Hayward (1995) as support for the assumption that soil represents 10 percent of the diet of free-range chickens.

Stephens, R.D., M.X. Petreas, and D.G. Hayward. 1992. "Biotransfer and Bioaccumulation of Dioxins and Dibenzofurans from Soil." Hazardous Materials Laboratory, California Department of Health Services. Berkeley, California.

This document is cited as the source of the assumption that free- range chickens ingest soil as 10 percent of their diet and as the source of the dioxin and furan congener-specific *BCFs*. However, this document does not clearly reference or document the assumption that soil represents 10 percent of a free-range chicken diet. The document appears to cite two other documents as supporting this assumption, Chang, Hayward, Goldman, Harnly, Flattery, and Stephens (1989) and Petreas, Goldman, Hayward, Chang, Flattery, Wiesmuller, Stephens, Fry, and Rappe (1992). Also, this document presents dioxin and furan congener-specific *BCFs* (egg yolk) for the low-exposure group after 80 days of a 178-day exposure period. The chickens in the low-dose group were fed a diet containing 10 percent soil with a PCDD/PCDF concentration of 42 parts per trillion (ppt) I-TEQ. Chickens in the high-dose group were fed a diet containing 10 percent soil with a PCDD/PCDF concentration of 458 ppt I-TEQ; *BCF* results were not presented for this group.

Stephens, R.D., M.X. Petreas, and D.G. Hayward. 1995. "Biotransfer and Bioaccumulation of Dioxins and Furnas from Soil: Chickens as a Model for Foraging Animals." *The Science of the Total Environment.* Volume 175: 253-273.

This document is an expansion of the results originally presented in Stephens, Petreas, and Hayward (1992). In particular, this document suggests that the percentage of soil in the diet of chickens raised under field conditions is likely to be greater than 10 percent, the value that was used in the experimental study presented in this document.

This document also presents dioxin and furan congener-specific *BCFs* (egg yolk) under two exposure schemes: low exposure and high exposure. The white leghorn (Babcock D 300) chickens in the low group were fed a diet containing 10 percent soil with a PCDD/PCDF concentration of 42 ppt I-TEQ. Chickens in the high group were fed a diet consisting of

10 percent soil with a PCDD/PCDF concentration of 460 ppt I-TEQ (some congeners were fortified by spiking). The *BCFs* presented for low- and high-dose groups both represent averages of results from Day-80, Day-160, and Day-178 (the end of the exposure duration).

U.S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA/600/6-90/003. January.

This document is a reference source for the equation in Table B-3-9; and an F_i value of 1.0.

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U.S. EPA (1995) recommends that uptake slope factors for the metals cadmium, selenium, and zinc cited by this document be used to derive Ba_{egg} values.

U.S. EPA. 1995. *Further Issues for Modeling the Indirect Exposure Impacts from Combustor Emissions.* Office of Research and Development. Washington, D.C. January 20.

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CONCENTRATION IN CHICKEN
(CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Description

This equation calculates the COPC concentration ($A_{chicken}$) in chicken meat due to ingestion of contaminated soil and grain by the free-range chickens.

Uncertainties associated with this equation include the following:

(1) This pathway has typically been applied only to PCDDs and PCDFs. However, concentrations in chickens for other organics and metals can be calculated using biotransfer factors using a similar approach as was used to calculate concentrations in other animal tissue.

(2) The assumption that 10 percent of a chicken's diet is soil may not represent site-specific or local conditions of chickens raised on subsistence farms. Stephens, Petreas, and Hayward (1995) suggests that the percentage of soil in the diet of chickens raised under field conditions may be greater than 10 percent. Therefore, the concentration of COPCs in chicken, $A_{chicken}$ may be underestimated.

(3) The recommended *BCFs* are based on incomplete experimental results. Stephens, Petreas, and Hayward (1995) presents results for a high-dose group and low-dose group (results are based on the full 178-day exposure period). A comparison of the results from Stephens, Petreas, and Hayward (1992) with those from Stephens, Petreas, and Hayward (1995) shows that BCPs from the high dose group are generally higher than *BCFs* from the low dose group. Therefore, use of the currently recommended *BCFs* may underestimate the COPC concentration in chicken, $A_{chicken}$.

Equation

$$A_{chicken} = \left(\sum (F_i \cdot Qp_i \cdot P_i) + Qs \cdot Cs \cdot Bs \right) \cdot Ba_{chicken}$$

For mercury modeling, the concentration of COPC in chicken is calculated for divalent mercury (Hg^{2+}) and methyl mercury (MHg) using their respective P_i, Cs, and $Ba_{chicken}$ values.

Variable	Description	Units	Value
$A_{chicken}$	Concentration of COPC in chicken meat	mg COPC/kg FW tissue	
F_i	Fraction of plant type *i* (grain) grown on contaminated soil and ingested by the animal	unitless	**1.0** This variable is site- and plant type-specific. F_i for chickens is estimated for grain feed only. U.S. EPA OSW recommends that a default value of 1.0 be used for all plant types. This is consistent with U.S. EPA (1990), U.S. EPA (1994a), U.S. EPA (1994b) and NC DEHNR (1997), which recommend that 100 percent of the plant materials ingested be assumed to have been grown on soil contaminated by facility emissions. The following uncertainty is associated with this variable: (1) 100 percent of the plant materials eaten by chickens are assumed to be grown on soil contaminated by facility emissions. This may overestimate $A_{chicken}$.

TABLE B-3-14

CONCENTRATION IN CHICKEN
(CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

Variable	Description	Units	Value
Qp_i	Quantity of plant type *i* (grain) ingested by the animal	kg DW plant/day	**0.2** Qp_i for chicken is estimated for grain feed only, as recommended by NC DEHNR (1997) and U.S. EPA (1990). Uncertainties associated with this variable include the following: (1) Actual grain ingestion rates can vary from site to site; this can over- or underestimate Qp_i.
P_i	Concentration of COPC in plant type *I* (grain)	mg COPC/kg DW	**Varies** This variable is COPC-, site-, and plant type-specific. Values for *Pi* are calculated for grain by using the equations in Table B-3-9. Uncertainties introduced by this variable include the following: (1) Some of the variables in the equation in Table B-3-9—including *Cs, Cyv, Q, Dydp*, and *Dywp*—are COPC- and site-specific. Uncertainties associated with these variables are site-specific. (2) In the equation in Table B-3-9, COPC-specific plant-soil biotransfer factors (*Br*) may not reflect site-specific conditions. This may be especially true for inorganic COPCs for which estimates of *Br* would be more accurately estimated by using plant uptake response slope factors.
Qs	Quantity of soil ingested by the animal	kg/day	**0.022** This variable is site-specific. U.S. EPA OSW recommends that the soil ingestion rate of 0.022 kg/day be used. This is consistent with Stephens, Petreas, and Hayward (1995). Uncertainties introduced by this variable include the following: (1) The recommended soil ingestion rate may not accurately represent site-specific or local conditions. (2) Empirical data to support soil ingestion rates of chickens are limited.
Cs	Average soil concentration over exposure duration	mg COPC/kg soil	**Varies** This variable is COPC- and site-specific, and should be calculated by using the equation in Table B-3-1. Uncertainties are site-specific.

Variable	Description	Units	Value
Bs	Soil bioavailability factor	unitless	**1.0** The soil bioavailability factor, *Bs*, can be thought of as the ratio between bioconcentration (or biotransfer) factors for soil and vegetation for a given COPC. The efficiency of transfer from soil may differ from efficiency or transfer from plant material for some COPCs. If the transfer efficiency is lower for soils, than this ratio would be less than 1.0. If it is equal or greater than that of vegetation, the *Bs* would be equal to or greater than 1.0. Due to limited data regarding bioavailability from soil, U.S. EPA OSW recommends a default value of 1.0 for *Bs*, until more COPC-specific data is available for this parameter. Some COPCs may be much less bioavailable from soil than from plant tissues. This uncertainty may overestimate *Bs*.
$Ba_{chicken}$	Biotransfer factor for chicken	day/kg FW tissue	**Varies** This variable is COPC-specific. Discussion of this variable and COPC-specific values are presented in Appendix A-3. $Ba_{chicken}$ is defined as the ratio of the COPC concentration in fresh weight tissue (mg COPC/kg FW tissue) to the daily intake of the COPC (mg COPC/day) from chicken feed. Uncertainties associated with this variable include the following: (1) U.S. EPA OSW recommends that $Ba_{chicken}$ values for organic COPCs other than dioxins and furans be calculated by using the regression equation developed on the basis of a study of 29 organic compounds. Values calculated by using this regression equation may not accurately represent the behavior of organic COPCs under site-specific conditions. Therefore, estimates of $Ba_{chicken}$ and, therefore, $A_{chicken}$ may be under- or overestimated to some degree. (2) The beef-to-chicken fat content ratio method which is used to estimate $Ba_{chicken}$ values from Ba_{beef} values for organics (except PCDDs and PCDFs) is based on the assumptions that (1) COPCs bioconcentrate in the fat tissues, and (2) there are no differences in metabolism or feeding characteristics between beef cattle and chicken. Due to uncertainties associated with these assumptions, $Ba_{chicken}$, and $A_{chicken}$ value may be under- or overestimated to some degree. (3) The recommended *BCFs* may not accurately represent the behavior of COPCs under site-specific or local conditions. For example, Stephens, Petreas, and Hayward (1995) note that chickens raised under field conditions, and which probably had more than 10 percent soil in their diet, showed larger apparent *BCFs*. Therefore, use of the recommended *BCFs* may underestimate the concentration of COPCs in chicken, $A_{chicken}$, to some extent. (4) The recommended *BCFs* are based on incomplete experimental results. Stephens, Petreas, and Hayward (1995) presents results that are based on the full 178-day exposure period. A comparison of the results from Stephens, Petreas, and Hayward (1992) with those from Stephens, Petreas, and Hayward (1995) shows that *BCFs* from the high-dose group are generally higher than *BCFs* from the low-dose group. Therefore, use of the currently recommended *BCFs* may underestimate the COPC concentration in chicken, $A_{chicken}$.

REFERENCES AND DISCUSSION

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This document appears to be cited by Stephens, Petreas, and Hayward (1992) as support for the assumption that soil represents 10 percent of the diet of free-range chickens.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is the reference source for the equation in Table B-3-14. This document also cites Stephens, Petreas, and Hayward (1992) as the source for the recommended fraction of diet that is soil (*Fd*) and $BCF_{Chicken}$ for dioxins and furan congeners.

Petreas, M.X., L. R. Goldman, D. G. Hayward, R. Chang, J. Flattery, T. Wiesmuller, R.D. Stephens, D.M. Fry, and C. Rappe. 1991. "Biotransfer and Bioaccumulation of PCDD/PCDFs from Soils: Controlled Exposure Studies of Chickens." *Chemosphere.* Volume 23: 1731-1741.

This document appears to be cited by Stephens, Petreas, and Hayward (1992) and Stephens, Petreas, and Hayward (1995) as support for the assumption that soil represents 10 percent of the diet of free-range chickens.

Stephens, R.D., M.X. Petreas, and D.G. Hayward. 1992. "Biotransfer and Bioaccumulation of Dioxins and Dibenzofurans from Soil." Hazardous Materials Laboratory, California Department of Health Services. Berkeley, California. Presented at the 12th International Symposium on Dioxins and Related Compounds. August 24 through 28. University of Tampere, Tampere, Finland.

This document is cited as the source of the assumption that free-range chickens ingest soil as 10 percent of their diet and as the source of the dioxin and furan congeners-specific *BCFs* recommended by NC DEHNR (1997). However this document does not clearly reference or document the assumption that soil represents 10 percent of a free-range chicken's diet. The document appears to cite two other documents as supporting its assumption, (1) Change, Hayward, Goldman, Harnly, Flattery and Stephens (1989) and (2) Petreas, Goldman, Hayward, Chang, Flattery, Wiesmuller, Stephens, Fry, and Rappe (1992).

This document also presents dioxin and furan congener-specific *BCFs* (thigh) for the low- exposure group after 80 days of a 178-day total exposure period. The chickens in the low-dose group were fed a diet containing 10 percent soil with a PCDD/PCDF concentration of 42 ppt I-TEQ. Chickens in the high-dose group were fed a diet containing 10 percent soil with a PCDD/PCDF concentration of 458 ppt I-TEQ; *BCF* results were not presented from the high-dose group.

Stephens, R.D., M.X. Petreas, and D.G. Hayward. 1995. "Biotransfer and Bioaccumulaton of Dioxins and Furans from Soil: Chickens as a Model for Foraging Animals." *The Science of the Total Environment.* Volume 175: 253-273.

This document is an expansion of the results originally presented in Stephens, Petreas, and Hayward (1992). In particular, this document suggests that the percentage of soil in the diet of chickens raised under field conditions is likely to be greater than 10 percent, the value that was used in the experimental study presented in this document.

This document also presents dioxin and furan congener-specific *BCFs* (thigh) under two exposure schemes—low exposure and high exposure. The white leghorn (Babcock D 300) chickens in the low group were fed a diet containing 10 percent soil with a PCDD/PCDF concentrations of 42 ppt I-TEQ. Chickens in the high group were fed a diet containing 10 percent soil with a PCDD/PCDF concentration of 460 ppt I-TEQ (some congeners were fortified by spiking).

The *BCFs* presented for low- and high-dose groups both represent averages of results from Day-80 and Day-164 of a total 178-day exposure period.

U.S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA/600/6-90/003. January.

This document is a reference source for the equation in Table B-3-9; and an F_i value of 1.0.

U.S. EPA. 1992. *Technical Support Document for Land Application of Sewage Sludge.* Volumes I and II. EPA 822/R-93-001a. Office of Water. Washington, D.C.

U.S. EPA (1995) recommends that uptake slope factors for the metals cadmium, selenium, and zinc cited by this document be used to derive $Ba_{chicken}$ values.

U.S. EPA. 1995. *Further Issues for Modeling the Indirect Exposure Impacts from Combustor Emissions.* Office of Research and Development. Washington, D.C. January 20.

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U.S. EPA. 1997b. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

TABLE B-4-1

WATERSHED SOIL CONCENTRATION DUE TO DEPOSITION (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Description
The equations in this table are used to calculate an average COPC soil concentration resulting from wet and dry deposition of particles and vapors to soil over the exposure duration. COPCs are assumed to be incorporated only to a finite depth (the soil mixing zone depth, Z_s). The COPC soil concentration averaged over the exposure duration, represented by *Cs*, should be used for carcinogenic COPCs, where the risk is averaged over the lifetime of an individual. Because the hazard quotient associated with noncarcinogenic COPCs is based on a reference dose rather than a lifetime exposure, the highest annual average COPC soil concentration occurring during the exposure duration period should be used for noncarcinogenic COPCs. The highest annual average COPC soil concentration would occur at the end of the time period of combustion and is represented by Cs_{tD}. The following uncertainties are associated with this variable: (1) The time period for deposition of COPCs resulting from hazardous waste combustion is assumed to be a conservative, long-term value. This assumption may overestimate *Cs* and Cs_{tD}. (2) Exposure duration values (T_2) are based on historical mobility studies and will not necessarily remain constant. Specifically, mobility studies indicate that most receptors that move remain in the vicinity of the combustion unit; however, it is impossible to accurately predict the probability that these short-distance moves will influence exposure, based on factors such as atmospheric transport of pollutants. (3) The use of a value of zero for T_1 does not account for exposure that may have occurred from historic operations and emissions from hazardous waste combustion. This may underestimate *Cs* and Cs_{tD}. (4) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils and, resulting a greater mixing depth. This uncertainty may overestimate *Cs* and Cs_{tD}. (5) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *Cs* and Cs_{tD}.

Equation for Carcinogens

Soil Concentration Averaged Over Exposure Duration

$$Cs = \frac{\left(\frac{Ds \cdot tD - Cs_{tD}}{ks}\right) + \left(\frac{Cs_{tD}}{ks} \cdot [1 - \exp(-ks\ (T_2 - tD))]\right)}{(T_2 - T_1)} \quad for\ T_1 < tD < T_2$$

$$Cs = \frac{Ds}{ks \cdot (tD - T_1)} \cdot \left(\left[tD + \frac{\exp(-ks \cdot tD)}{ks} \right] - \left[T_1 + \frac{\exp(-ks \cdot T_1)}{ks} \right] \right) \quad for\ T_2 \leq tD$$

WATERSHED SOIL CONCENTRATION DUE TO DEPOSITION (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Equation for Noncarcinogens

Highest Annual Average Soil Concentration

$$Cs_{tD} = \frac{Ds \cdot [1 - \exp(-ks \cdot tD)]}{ks}$$

where

$$Ds = \frac{100 \cdot Q}{Z_s \cdot BD} \cdot [F_v \, (0.31536 \cdot Vdv \cdot Cywv + Dywwv) + Dytwp \cdot (1 - F_v)]$$

For mercury modeling

$$Ds = \frac{100 \cdot (0.48Q)}{Z_s \cdot BD} \cdot [F_v \, (0.31536 \cdot Vdv \cdot Cyv + Dywv) + (Dydp + Dywp) \cdot (1 - F_v)]$$

Use *0.48Q* for total mercury and $F_v = 0.85$ in the mercury modeling equation to calculate *Ds*. The calculated *Ds* value is apportioned into the divalent mercury (Hg^{2+}) and methyl mercury (MHg) forms based on the assumed 98% Hg^{2+} and 2% MHg speciation split in soils (see Chapter 2). Elemental mercury (Hg^0) occurs in very small amounts in the vapor phase and does not exist in the particle or particle bound phase. Therefore, elemental mercury deposition onto soils is assumed to be negligible or zero. Elemental mercury is evaluated for the direct inhalation pathway only (Table B-5-1).

Ds (Hg^{2+})	=	0.98 *Ds*
Ds (Mhg)	=	0.02 *Ds*
Ds (Hg^0)	=	0.0

Evaluate divalent and methyl mercury as individual COPCs. Calculate *Cs* for divalent and methyl mercury using the corresponding (1) fate and transport parameters for mercuric chloride (divalent mercury) and methyl mercury provided in Appendix A-3, and (2) *Ds* (Hg^{2+}) and *Ds* (MHg) as calculated above.

Variable	Description	Units	Value
Cs	Average soil concentration over exposure duration	mg COPC/kg soil	

TABLE B-4-1

WATERSHED SOIL CONCENTRATION DUE TO DEPOSITION (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
Cs_{tD}	Soil concentration at time *tD*	mg COPC/kg soil	
Ds	Deposition term	mg COPC/kg soil-yr	**Varies** U.S. EPA (1994a) and NC DEHNR (1991) recommend incorporating the use of a deposition term into the *Cs* equation. Uncertainties associated with this variable include the following: (1) Five of the variables in the equation for *Ds* (*Q, Cyv, Dywv, Dywp*, and *Dydp*) are COPC- and site-specific. Values of these variables are estimated on the basis of modeling. The direction and magnitude of any uncertainties should not be generalized. (2) Based on the narrow recommended ranges, uncertainties associated with *Vdv*, F_v, and *BD* are expected to be low. (3) Values for Z_s vary by about one order of magnitude. Uncertainty is greatly reduced if it is known whether soils are tilled or untilled.
tD	Time period over which deposition occurs (time period of combustion)	yr	**100** U.S. EPA (1990a) specifies that this period of time can be represented by periods of 30, 60 or 100 years. U.S. EPA OSW recommends that facilities use the conservative value of 100 years unless site-specific information is available indicating that this assumption is unreasonable (see Chapter 6 of the HHRAP Protocol).
ks	COPC soil loss constant due to all processes	yr^{-1}	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-4-2. The COPC soil loss constant is the sum of all COPC removal processes. Uncertainty associated with this variable includes the following: COPC-specific values for *ksg* (one of the variables in the equation in Table B-4-2) are empirically determined from field studies. No information is available regarding the application of these values to the site-specific conditions associated with affected facilities.

Variable	Description	Units	Value
T_2	Length of exposure duration	yr	**6, 30, or 40** U.S. EPA OSW recommends the following reasonable maximum exposure (RME) values for T_2: Exposure Duration / RME / Reference Child Resident, Subsistence Farmer Child, Subsistence Fisher Child — 6 years — U.S. EPA (1990b) Adult Resident and Subsistence Fisher — 30 years (6 child and 24 adult) — U.S. EPA (1990b) Subsistence Farmer — 40 years — U.S. EPA (1994b) U.S. EPA (1994c) recommended the following unreferenced values: Exposure Duration / Years Subsistence Farmer — 40 Adult Resident — 30 Subsistence Fisher — 30 Child Resident — 9 Uncertainties associated with this variable include the following: (1) Exposure duration rates are based on historical mobility rates and may not remain constant. This assumption may overestimate or underestimate Cs and Cs_{tD}. (2) Mobility studies indicate that most receptors that move remain in the vicinity of the emission sources; however, it is impossible to accurately predict the likelihood that these short-distance moves will influence exposure, based on factors such as atmospheric transport of pollutants. This assumption may overestimate or underestimate Cs and Cs_{tD}.
T_1	Time period at the beginning of combustion	yr	**0** Consistent with U.S. EPA (1994c), U.S. EPA OSW recommends a value of 0 for T_1. The following uncertainty is associated with this variable: The use of a value of 0 for T_1 does not account for exposure that may have occurred from historical operation or emissions from the combustion of hazardous waste. This may underestimate Cs and Cs_{tD}.

Variable	Description	Units	Value
100	Units conversion factor	$mg\text{-}cm^2/kg\text{-}cm^2$	
Q	COPC emission rate	g/s	**Varies** This variable is COPC- and site-specific. See Chapters 2 and 3 of the HHRAP for guidance regarding the calculation of this variable. Uncertainties associated with this variable are site-specific.
Z_s	Soil mixing zone depth	cm	**1 to 20** U.S. EPA OSW recommends the following values for this variable: <u>Soil</u> — <u>Depth (cm)</u> — <u>Reference</u> Untilled — 1 — U.S. EPA (1990a) and U.S. EPA (1993a) Tilled — 20 — U.S. EPA (1990a) and U.S. EPA (1993a) U.S. EPA (1990a) does not include a reference for these values. U.S. EPA (1993a) cites U.S. EPA (1992). The following uncertainties are associated with this variable: (1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting a greater mixing depth. This uncertainty may overestimate *Cs* and Cs_{tD}. (2) Deposition to hard surfaces may result in dust residues that have negligible dilution in comparison to that of other residues. This uncertainty may underestimate *Cs* and Cs_{tD}.
BD	Soil bulk density	g soil/cm^3 soil	**1.5** This variable is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil (Hillel 1980), as summarized in U.S. EPA (1990a). A range of 0.83 to 1.84 was originally cited in Hoffman and Baes (1979). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g/cm^3, based on a mean value for loam soil that was obtained from Carsel, Parrish, Jones, Hansen, and Lamb (1988). The value of 1.5 g/cm^3 also represents the midpoint of the "relatively narrow range" for *BD* of 1.2 to 1.7 g/cm^3 (U.S. EPA 1993a). The following uncertainty is associated with this variable: The recommended *BD* value may not accurately represent site-specific soil conditions; and may under- or overestimate site-specific soil conditions to an unknown degree.

TABLE B-4-1

WATERSHED SOIL CONCENTRATION DUE TO DEPOSITION (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
F_v	Fraction of COPC air concentration in vapor phase	unitless	**0 to 1** This variable is COPC-specific. Discussion of this variable and COPC-specific values is presented in Appendix A-3. This range is based on values presented in Appendix A-3. Values are also presented in U.S. EPA (1994b) and NC DEHNR (1997). F_v was calculated using an equation presented in Junge (1977) for all organic COPCs, including PCDDs and PCDFs. U.S. EPA (1994c) states that $F_v = 0$ for all metals (except mercury). The following uncertainties are associated with this variable: (1) It is based on the assumption of a default S_T value for background plus local sources, rather than an S_T value for urban sources. If a specific site is located in an urban area, the use of the latter S_T value may be more appropriate. Specifically, the S_T value for urban sources is about one order of magnitude greater than that for background plus local sources, and it would result in a lower calculated F_v value; however, the F_v value is likely to be only a few percent lower. (2) According to Bidleman (1988), the equation used to calculate F_v assumes that the variable c (Junge constant) is constant for all chemicals; however, the value of c depends on the chemical (sorbate) molecular weight, the surface concentration for monolayer coverage, and the difference between the heat of desorption from the particle surface and the heat of vaporization of the liquid-phase sorbate. To the extent that site- or COPC-specific conditions may cause the value of c to vary, uncertainty is introduced if a constant value of c is used to calculate F_v.
0.31536	Units conversion factor	m-g-s/cm-μg-yr	
Vdv	Dry deposition velocity	cm/s	**3** U.S. EPA (1994c) recommended the use of 3 cm/s for the dry deposition velocity, based on median dry deposition velocity for HNO_3 from an unspecified U.S. EPA database of dry deposition velocities for HNO_3, ozone, and SO_2. HNO_3 was considered the most similar to the COPCs recommended for consideration in the HHRAP. The value should be applicable to any organic COPC with a low Henry's Law Constant. The following uncertainty is associated with this variable: (1) HNO_3 may not adequately represent specific COPCs; therefore, the use of a single value may under- or overestimate estimated soil concentration.
Cywv	Unitized yearly (water body or watershed) average air concentration from vapor phase	μg-s/g-m^3	**Varies** This variable is COPC- and site-specific, and is determined by air modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.

TABLE B-4-1

WATERSHED SOIL CONCENTRATION DUE TO DEPOSITION
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
Dywwv	Unitized yearly (water body or watershed) average wet deposition from vapor phase	s/m^2-yr	**Varies** This variable is COPC- and site-specific, and is determined by air modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.
Dytwp	Unitized yearly (water body or watershed) average total (wet and dry) deposition from particle phase	s/m^2-yr	**Varies** This variable is COPC- and site-specific, and is determined by air modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.

REFERENCES AND DISCUSSION

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For discussion, see References and Discussion, Table B-1-1.

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NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This is one of the source documents for the equation in Table B-4-1. This document also recommends the use of (1) a deposition term, *Ds*, and (2) COPC-specific F_v (fraction of COPC air concentration in vapor phase) values.

Research Triangle Institute (RTI). 1992. *Preliminary Soil Action Level for Superfund Sites.* Draft Interim Report. Prepared for U.S. EPA Hazardous Site Control Division, Remedial Operations Guidance Branch. Arlington, Virginia. EPA Contract 68-W1-0021. Work Assignment No. B-03, Work Assignment Manager Loren Henning. December.

This document is a reference source for COPC-specific F_v (fraction of COPC air concentration in vapor phase) values.

U.S. EPA. 1990a. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600-90-003. January.

This document is a reference source for the equation in TableB-4-1, and it recommends that (1) the time period over which deposition occurs (time period for combustion), *tD*, be represented by periods of 30, 60 and 100 years, and (2) undocumented values for soil mixing zone depth, Z_s, for tilled and untilled soil.

U.S. EPA. 1990b. *Exposure Factors Handbook.* March.

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This document is cited by U.S. EPA (1993a) as the source of values for soil mixing zone depth, Z_s, for tilled and untilled soils.

U.S. EPA. 1993a. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, D.C. November.

This document is a reference for recommended values for soil mixing zone depth, Z_s, for tilled and untilled soils; it cites U.S. EPA (1992) as the source of these values. It also recommends a "relatively narrow" range for soil bulk density, *BD*, of 1.2 to 1.7 g soil/cm^3 soil.

U.S. EPA. 1993b. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Working Group Recommendations. Office of Solid Waste. Office of Research and Development. Washington, D.C. September 24.

This document is a reference for the equation in Table B-4-1. It recommends using a deposition term, *Ds*, and COPC-specific F_v values (fraction of COPC air concentration in vapor phase) in the *Cs* equation.

U.S. EPA 1994a. *Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. April 15.

This document is a reference for the equation in Table B-4-1; it recommends that the following be used in the *Cs* equation: (1) a deposition term, *Ds*, and (2) a default soil bulk density value of 1.5 (g soil/cm^3 soil), based on a mean value for loam soil from Carsel, Parrish, Jones, Hansen, and Lamb (1988).

U.S. EPA. 1994b. *Estimating Exposure to Dioxin-Like Compounds. Volume III: Site-Specific Assessment Procedures.* External Review Draft. Office of Research and Development. Washington, D.C. June. EPA/600/6-88/005Cc.

This document recommends values for length of exposure duration, T_2, for the subsistence farmer.

U.S. EPA. 1994c. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

The value for dry deposition velocity is based on median dry deposition velocity for HNO_3 from a U.S. EPA database of dry deposition velocities for HNO3 ozone, and SO_2. HNO_3 was considered the most similar to the constituents covered and the value should be applicable to any organic compound having a low Henry's Law Constant. The reference document for this recommendation was not cited. This document recommends the following:

- Values for the length of exposure duration, T_2
- Value of 0 for the time period of the beginning of combustion, T_1
- F_v values (fraction of COPC air concentration in vapor phase) that range from 0.27 to 1 for organic COPCs
- *Vdv* value (dry deposition velocity) of 3 cm/s (however, no reference is provided for this recommendation)

- Default soil bulk density value of 1.5 (g soil/cm^3 soil), based on a mean for loam soil from Carsel, Parrish, Jones, Hansen, and Lamb (1988)
- *Vdv* value of 3 cm/s, based on median dry deposition velocity for HNO_3 from an unspecified U.S. EPA database of dry deposition velocities for HNO_3, ozone, and SO_2. HNO_3 was considered the most similar to the COPCs recommended for consideration in the HHRAP.

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

TABLE B-4-2

COPC SOIL LOSS CONSTANT
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Description

This equation calculates the COPC soil loss constant, which accounts for the loss of COPCs from soil by several mechanisms.

Uncertainties associated with this equation include the following:

(1) COPC-specific values for *ksg* are empirically determined from field studies; no information is available regarding the application of these values to the site-specific conditions associated with affected facilities.
(2) The source of the equations in Tables B-4-3 through B-4-6 have not been identified.

Equation

$$ks = ksg + kse + ksr + ksl + ksv$$

Variable	Description	Units	Value
ks	COPC soil loss constant due to all processes	yr^{-1}	
ksg	COPC loss constant due to biotic and abiotic degradation	yr^{-1}	**Varies** This variable is COPC-specific and should be determined from the COPC tables in Appendix A-3. "Degradation rate" values are also presented in NC DEHNR (1997), however, no reference or source is provided for the values. U.S. EPA (1994a) and U.S. EPA (1994b) state that *ksg* values are COPC-specific; however, all *ksg* values are presented as zero (U.S. EPA 1994a) or as "NA" (U.S. EPA 1994b); the basis of these assumptions is not addressed. The following uncertainty is associated with this variable: COPC-specific values for *ksg* are empirically determined from field studies; no information is available regarding the application of these values to the site-specific conditions associated with affected facilities.

TABLE B-4-2

COPC SOIL LOSS CONSTANT
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
kse	COPC loss constant due to soil erosion	yr^{-1}	**0** This variable is COPC- and site-specific, and is further discussed in Table B-4-3. Consistent with U.S. EPA (1994a), U.S. EPA (1994b) and NC DEHNR (1997), U.S. EPA OSW recommends that the default value assumed for *kse* is zero because of contaminated soil eroding onto the site and away from the site. Uncertainties associated with this variable include the following: (1) The source of the equation in Table B-4-3 has not been identified. (2) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting a greater mixing depth. This uncertainty may overestimate *kse*. (3) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *kse*.
ksr	COPC loss constant due to surface runoff	yr^{-1}	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-4-4. No reference document is cited for this equation; the use of this equation is consistent with U.S. EPA (1994b) and NC DEHNR (1997). U.S. EPA (1994a) states that all *ksr* values are zero but does not explain the basis of this assumption. Uncertainties associated with this variable (calculated by using Table B-4-4) include the following: (1) The source of Table B-4-4 has not been identified. (2) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksr*. (3) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksr*.
ksl	COPC loss constant due to leaching	yr^{-1}	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-4-5. The use of this equation is consistent with U.S. EPA (1993), U.S. EPA(1994b), and NC DEHNR (1997). U.S. EPA (1994a) states that all *ksl* values are zero but does not explain the basis of this assumption. Uncertainties associated with this variable (calculated by using Table B-4-5) include the following: (1) The source of Table B-4-5 has not been identified. (2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in-situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksl*.

Variable	Description	Units	Value
ksv	COPC loss constant due to volatilization	yr^{-1}	**0** This variable is COPC- and site-specific, and is further discussed in Table B-4-6. Consistent with U.S. EPA guidance (1994a) and based on the need for additional research to be conducted to determine the magnitude of the uncertainty introduced for modeling volatile COPCs from soil, U.S. EPA OSW recommends that, until identification and validation of more applicable models, the constant for the loss of soil resulting from volatilization (*ksv*) should be set equal to zero. Uncertainties associated with this variable include the following: (1) The source of the equation in Table B-4-6 has not been identified. (2) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting a greater mixing depth. This uncertainty may overestimate *ksv*. (3) Deposition to hard surfaces may result in dust residues that have negligible dilution, (as a result of potential mixing with in-situ materials) in comparison to that of other residues. This uncertainty may underestimate *ksv*.

COPC SOIL LOSS CONSTANT
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

REFERENCES AND DISCUSSION

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is one of the reference documents for Tables B-4-4, B-4-5, and B-4-6. This document is also cited as (1) the source for a range of COPC-specific degradation rates (*ksg*), and (2) one of the sources that recommend using the assumption that the loss resulting from erosion (*kse*) is zero because of contaminated soil eroding onto the site and away from the site.

U.S. EPA. 1993c. *Review Draft Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Office of Health and Environmental Assessment. Office of Research and Development. EPA-600-AP-93-003. November 10.

This document is one of the reference documents for Tables B-4-3 and B-4-5.

U.S. EPA. 1994a. *Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* April 15.

This document is cited as a source for the assumptions that losses resulting from erosion (*kse*), surface runoff (*ksr*), degradation (*ksg*), leaching (*ksl*), and volatilization (*ksv*) are all zero.

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document is one of the reference documents for Tables B-4-4, B-4-5, and B-4-6. This document is also cited as one of the sources that recommend using the assumption that the loss resulting from erosion (*kse*) is zero and the loss resulting from degradation (*ksg*) is "NA" or zero for all compounds.

COPC LOSS CONSTANT DUE TO SOIL EROSION
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Description

This equation calculates the constant for COPC loss resulting from erosion of soil. Consistent with U.S. EPA (1994), U.S. EPA (1994b), and NC DEHNR (1997), U.S. EPA OSW recommends that the default value assumed for *kse* is zero because of contaminated soil eroding onto the site and away from the site. In site-specific cases where the permitting authority considers it appropriate to calculate a *kse*, the following equation presented in this table should be considered along with associated uncertainties. Additional discussion on the determination of *kse* can be obtained from review of the methodologies described in U.S. EPA NCEA document, *Methodology for Assessing Health Risks Associated with Multiple Exposure Pathways to Combustor Emissions* (In Press). Uncertainties associated with this equation include:

(1) For soluble COPCs, leaching might lead to movement below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *kse*.
(2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *kse*.

Equation

$$kse = \frac{0.1 \cdot X_e \cdot SD \cdot ER}{BD \cdot Z_s} \cdot \left(\frac{Kd_s \cdot BD}{\theta_{sw} + (Kd_s \cdot BD)} \right)$$

Variable	Description	Units	Value
kse	COPC loss constant due to soil erosion	yr^{-1}	**0** Consistent with U.S. EPA (1994), U.S. EPA (1994b), and NC DEHNR (1997), U.S. EPA OSW recommends that the default value assumed for *kse* is zero because of contaminated soil eroding onto the site and away from the site. uncertainty may overestimate *kse*.
X_e	Unit soil loss	kg/m^2-yr	**Varies** This variable is site-specific and is calculated by using the equation in Table B-4-13. The following uncertainty is associated with this variable: All of the equation variables are site-specific. Use of default values rather than site-specific values for any or all of these variables will result in unit soil loss (X_e) estimates that are under- or overestimated to some degree. Based on default values, X_e estimates can vary over a range of less than two orders of magnitude.

Variable	Description	Units	Value
SD	Sediment delivery ratio	unitless	**Varies** This value is site-specific and is calculated by using the equation in Table B-4-14. Uncertainties associated with this variable include the following: (1) The recommended default values for the empirical intercept coefficient, *a*, are average values that are based on studies of sediment yields from various watersheds. Therefore, those default values may not accurately represent site-specific watershed conditions. As a result, use of these default values may under- or overestimate *SD*. (2) The recommended default value for the empirical slope coefficient, *b*, is based on a review of sediment yields from various watersheds. This single default value may not accurately represent site-specific watershed conditions. As a result, use of this default value may under- or overestimate *SD*.
ER	Soil enrichment ratio	unitless	**Inorganics: 1** **Organics: 3** COPC enrichment occurs because (1) lighter soil particles erode more than heavier soil particles, and (2) concentration of organic COPCs—which is a function of organic carbon content of sorbing media—is expected to be higher in eroded material than in *in situ* soil (U.S. EPA 1993). In the absence of site-specific data, U.S. EPA OSW recommends a default value of 3 for organic COPCs and 1 for inorganic COPCs. This is consistent with other U.S. EPA guidance (1993), which recommends a range of 1 to 5 and a value of 3 as a "reasonable first estimate." This range has been used for organic matter, phosphorus, and other soil-bound COPCs (U.S. EPA 1993); however, no sources or references were provided for this range. *ER* is generally higher in sandy soils than in silty or loamy soils (U.S. EPA 1993). The following uncertainty is associated with this variable: The default *ER* value may not accurately reflect site-specific conditions; therefore, *kse* may be over- or underestimated to an unknown extent. The extent of any uncertainties will be reduced by using county-specific *ER* values.
BD	Soil bulk density	g soil/cm^3 soil	**1.5** This variable is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil (Hillel 1980), as summarized in U.S. EPA (1990). A range of 0.83 to 1.84 was originally cited in Hoffman and Baes (1979). U.S. EPA (1994b) recommended a default *BD* value of 1.5 g/cm^3, based on a mean value for loam soil that was taken from Carsel, Parrish, Jones, Hansen, and Lamb (1988). The value of 1.5 g/cm^3 also represents the midpoint of the "relatively narrow range" for *BD* of 1.2 to 1.7 g/cm^3 (U.S. EPA 1993). The following uncertainty is associated with this variable: The recommended soil bulk density value may not accurately represent site-specific soil conditions.

TABLE B-4-3

COPC LOSS CONSTANT DUE TO SOIL EROSION (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
Z_s	Soil mixing zone depth	cm	**1 to 20** U.S. EPA recommends the following values for this variable: Soil / Depth (cm) / Reference Untilled / 1 / U.S. EPA (1990a) and U.S. EPA (1993a) Tilled / 20 / U.S. EPA (1990a) and U.S. EPA (1993a) U.S. EPA (1990) does not provide a reference for these values. U.S. EPA (1993) cites U.S. EPA (1994a). Uncertainties associated with this variable include the following: (1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksr*. (2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *kse*.
Kd_s	Soil-water partition coefficient	mL water/g soil (or cm^3 water/g soil)	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Uncertainties associated with this parameter will be limited if Kd_s values are calculated as described in Appendix A-3.
θ_{sw}	Soil volumetric water content	mL water/cm^3 soil	**0.2** This variable is site-specific, and depends on the available water and on soil structure; θ_{sw} can be estimated as the midpoint between a soil's field capacity and wilting point, if a representative watershed soil can be identified. However, U.S. EPA OSW recommends the use of 0.2 mL/cm^3 as a default value. This value is the midpoint of the range 0.1 (very sandy soils) to 0.3 (heavy loam/clay soils) recommended by U.S. EPA (1993) (no source or reference is provided for this range) and is consistent with U.S. EPA (1994b). The following uncertainty is associated with this variable: The default θ_{sw} value may not accurately reflect site-specific or local conditions; therefore, *kse* may be under- or overestimated to a small extent, based on the limited range of values.

REFERENCES AND DISCUSSION

Carsel, R.F., R.S. Parish, R.L. Jones, J.L. Hansen, and R.L. Lamb. 1988. "Characterizing the Uncertainty of Pesticide Leaching in Agricultural Soils." *Journal of Contaminant Hydrology*. Vol. 2. Pages 11-24.

This document is cited by U.S. EPA (1994b) as the source for a mean soil bulk density, *BD*, value of 1.5 (g soil/cm^3 soil) for loam soil.

Hillel, D. 1980. *Fundamentals of Soil Physics*. Academic Press, Inc. New York.

This document is cited by U.S. EPA (1990) for the statement that soil bulk density, *BD*, is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil.

Hoffman, F.O., and C.F. Baes. 1979. *A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides*. ORNL/NUREG/TM-882.

This document presents a soil bulk density, *BD*, range of 0.83 to 1.84.

U.S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions*. Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600-90-003. January.

This document presents a range of values for soil mixing zone depth, Z_s, for tilled and untilled soil. The basis or source of these values is not identified.

U.S. EPA. 1993. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions*. External Review Draft. Office of Research and Development. Washington, D.C. November 1993.

This document is the source of a range of COPC enrichment ratio, *ER*, values. The recommended range, 1 to 5, has been used for organic matter, phosphorous, and other soil-bound COPCs. This document recommends a value of 3 as a "reasonable first estimate," and states that COPC enrichment occurs because lighter soil particles erode more than heavier soil particles. Lighter soil particles have higher ratios of surface area to volume and are higher in organic matter content. Therefore, concentration of organic COPCs, which is a function of the organic carbon content of sorbing media, is expected to be higher in eroded material than in *in situ* soil.

This document is also a source of the following:

- A "relatively narrow range" for soil bulk density, *BD*, of 1.2 to 1.7 (g soil/cm^3 water)
- COPC-specific (inorganic COPCs only) Kd_s values used to develop a proposed range (2 to 280,000 [mL water/g soil]) of Kd_s values
- A range of soil volumetric water content (θ_{sw}) values of 0.1 (mL water/cm^3 soil) (very sandy soils) to 0.3 (mL water/cm^3 soil) (heavy loam/clay soils) (however, no source or reference is provided for this range)
- A range of values for soil mixing zone depth, Z_s, for tilled and untilled soil

U.S. EPA. 1994. *Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities*. April 15.

U.S. EPA. 1994a. *Estimating Exposure to Dioxin-Like Compounds. Volume III: Site-specific Assessment Procedures.* External Review Draft. Office of Research and Development. Washington, D.C. EPA/600/6-88/005Cc. June.

This document is the source of values for soil mixing zone depth, Z_s, for tilled and untilled soil, as cited in U.S. EPA (1993).

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document recommends (1) a default soil bulk density value of 1.5 (g soil/cm^3 soil), based on a mean value for loam soil that is taken from Carsel, Parrish, Jones, Hansen, and Lamb (1988), and (2) a default soil volumetric water content, θ_{sw}, value of 0.2 (mL water/cm^3 soil), based on U.S. EPA (1993).

TABLE B-4-4

COPC LOSS CONSTANT DUE TO RUNOFF
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Description

This equation calculates the COPC loss constant due to runoff of soil. Uncertainties associated with this equation include the following:

(1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksr*.
(2) Deposition to hard surfaces may result in dust residues that have negligible dilution, in comparison to that of other residues. This uncertainty may underestimate *ksr*.

Equation

$$ksr = \frac{RO}{\theta_{sw} \cdot Z_s} \cdot \left(\frac{1}{1 + \left(Kd_s \cdot BD / \theta_{sw} \right)} \right)$$

Variable	Description	Units	Value
ksr	COPC loss constant due to runoff	yr^{-1}	
RO	Average annual surface runoff from pervious areas	cm/yr	**Varies** This variable is site-specific. According to U.S. EPA (1993), U.S. EPA (1994a), and NC DEHNR (1997), average annual surface runoff, *RO*, can be estimated by using the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973). According to NC DEHNR (1997), estimates can also be made by using more detailed, site-specific procedures for estimating the amount of surface runoff, such as those based on the U.S. Soil Conservation Service curve number equation (CNE). U.S. EPA (1985) is cited as an example of such a procedure. The following uncertainty is associated with this variable: To the extent that site-specific or local average annual surface runoff information is not available, default or estimated values may not accurately represent site-specific or local conditions. As a result, *ksl* may be under- or overestimated to an unknown degree.

Variable	Description	Units	Value
θ_{sw}	Soil volumetric water content	mL water/cm^3 soil	**0.2** This variable depends on the available water and soil structure; if a representative watershed soil can be identified, θ_{sw} can be estimated as the midpoint between a soil's field capacity and wilting point. U.S. EPA OSW recommends the use of 0.2 mL/cm^3 as a default value. This value is the midpoint of the range 0.1 (very sandy soils) to 0.3 (heavy loam/clay soils), which is recommended by U.S. EPA (1993) (no source or reference is provided for this range), and is consistent with U.S. EPA (1994a) and NC DEHNR (1997). The following uncertainty is associated with this variable: The default θ_{sw} value may not accurately reflect site-specific or local conditions; therefore, *kse* may be under- or overestimated to a small extent, based on the limited range of values.
Z_s	Soil mixing zone depth	cm	**1 to 20** U.S. EPA OSW recommends the following values for this variable: Soil / Depth (cm) / Reference Untilled / 1 / U.S. EPA (1990a) and U.S. EPA (1993a) Tilled / 20 / U.S. EPA (1990a) and U.S. EPA (1993a) U.S. EPA (1990) does not provide a reference for these values. U.S. EPA (1993) cites U.S. EPA (1994b). Uncertainties associated with this variable include the following: (1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksr*. (2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in-situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksr*.
Kd_s	Soil-water partition coefficient	mL water/g soil (or cm^3 water/g soil)	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Uncertainties associated with this parameter will be limited if Kd_s values are calculated as described in Appendix A-3.

Variable	Description	Units	Value
BD	Soil bulk density	g soil/cm^3 soil	**1.5** This variable is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil (Hillel 1980), as summarized in U.S. EPA (1990). A range of 0.83 to 1.84 was originally cited in Hoffman and Baes (1979). U.S. EPA (1994a) recommended a default soil bulk density value of 1.5 g/cm^3, based on a mean value for loam soil that is taken from Carsel, Parrish, Jones, Hansen, and Lamb (1988). The value of 1.5 g/cm^3 also represents the midpoint of the "relatively narrow range" for BD of 1.2 to 1.7 g/cm^3 (U.S. EPA 1993). The following uncertainty is associated with this variable: The recommended soil bulk density value may not accurately represent site-specific soil conditions.

REFERENCES AND DISCUSSION

Carsel, R.F., R.S. Parrish, R.L. Jones, J.L. Hansen, and R.L. Lamb. 1988. "Characterizing the Uncertainty of Pesticide Leaching in Agricultural Soils." *Journal of Contaminant Hydrology*. Vol. 2. Pages 11-24.

This document is cited by U.S. EPA (1994a) as the source of a mean soil bulk density, *BD*, value of 1.5 (g soil/cm^3 soil) for loam soil.

Geraghty, J.J., D.W. Miller, F. Van der Leeden, and F.L. Troise. 1973. *Water Atlas of the United States.* Water Information Center, Port Washington, New York.

This document is cited by U.S. EPA (1993), U.S. EPA (1994), and NC DEHNR (1997) as a reference to calculate average annual runoff, *RO.* This reference provides maps with isolines of annual average surface water runoff, which is defined as all flow contributions to surface water bodies, including direct runoff, shallow interflow, and ground water recharge. Because these values are total contributions and not only surface runoff, U.S. EPA (1994) recommends that the volumes be reduced by 50 percent in order to estimate surface runoff.

Hillel, D. 1980. Fundamentals of Soil Physics. Academic Press, Inc. New York.

This document is cited by U.S. EPA (1990) for the statement that dry soil bulk density, *BD*, is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil.

Hoffman, F.O., and C.F. Baes. 1979. *A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides.* ORNL/NUREG/TM-882.

This document presents a soil bulk density, *BD*, range of 0.83 to 1.84.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is one of the source documents that cites the use of Table B-4-4; however, this document is not the original source of this equation (this source is unknown). This document also recommends the following:

- Estimation of annual current runoff, *RO* (cm/yr), by using the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973) or site-specific procedures, such as using the U.S. Soil Conservation Service curve number equation (CNE); U.S. EPA (1985) is cited as an example of such a procedure.
- Default value of 0.2 (mL water/cm^3 soil) for soil volumetric water content (θ_{sw})

U.S. EPA. 1985. *Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water—Part I (Revised. 1985).* Environmental Research Laboratory. Athens, Georgia. EPA/600/6-85/002a. September.

This document is cited by NC DEHNR (1997) as an example of the use of the U.S. Soil Conservation Service CNE to estimate site-specific surface runoff.

U.S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600-90-003. January.

This document presents a range of values for soil mixing zone depth, Z_s, for tilled and untilled soil; the basis for, or sources of, these values is not identified.

U.S. EPA. 1993. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, D.C. November.

This document recommends the following:

- A "relatively narrow range" for soil bulk density, *BD*, of 1.2 to 1.7 (g soil/cm^3 soil)
- A range of soil volumetric water content, θ_{sw}, values of 0.1 (very sandy soils) to 0.3 (heavy loam/clay soils) (the original source of, or reference for, these values is not identified)
- A range of values for soil mixing depth, Z_s, for tilled and untilled soil (the original source of, or reference for, these values is not identified)
- A range (2 to 280,000 [mL water/g soil]) of Kd_s values for inorganic COPCs
- Use of the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973) to calculate average annual runoff, *RO*.

U.S. EPA. 1994b. *Estimating Exposure to Dioxin-Like Compounds. Volume III: Site-specific Assessment Procedures.* External Review Draft. Office of Research and Development. Washington, D.C. EPA/600/6-88/005Cc. June.

This document presents a range of values for soil mixing zone depth, Z_s, for tilled and untilled soil as cited in U.S. EPA (1993).

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes.* Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities. Offices of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document recommends the following:

- Estimation of average annual runoff, *RO*, by using the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973)
- Default soil dry bulk density, *BD*, value of 1.5 (g soil/cm^3 soil), based on the mean for loam soil that is taken from Carsel, Parrish, Jones, Hansen, and Lamb (1988)
- Default soil volumetric water content, θ_{sw}, value of 0.2 (mL water/cm^3 soil), based on U.S. EPA (1993)

TABLE B-4-5

COPC LOSS CONSTANT DUE TO LEACHING
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Description

This equation calculates the COPC loss constant due to leaching of soil. Uncertainties associated with this equation include the following:

(1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksl*.

(2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *insitu* materials) in comparison to that of other residues. This uncertainty may underestimate *ksl*.

(3) The original source of this equation has not been identified. U.S. EPA (1993) presents the equation as shown here. U.S. EPA (1994a) and NC DEHNR (1997) replaced the numerator as shown with "*q*", defined as average annual recharge (cm/yr).

Equation

$$ksl = \frac{P + I - RO - E_v}{\theta_{sw} \cdot Z_s \cdot \left[1.0 + \left(BD \cdot Kd_s / \theta_{sw}\right)\right]}$$

Variable	Description	Units	Value
ksl	COPC loss constant due to leaching	yr^{-1}	
P	Average annual precipitation	cm/yr	**18.06 to 164.19** This variable is site-specific. This range is based on information presented in U.S. EPA (1990), representing data for 69 selected cities (U.S. Bureau of Census 1987; Baes, Sharp, Sjoreen and Shor 1984). The 69 selected cities are not identified; however, they appear to be located throughout the continental United States. U.S. EPA OSW recommends that site-specific data be used. The following uncertainty is associated with this variable: To the extent that a site is not located near an established meteorological data station, and site-specific data are not available, default average annual precipitation data may not accurately reflect site-specific conditions. As a result, *ksl* may be under- or overestimated. However, average annual precipitation data are reasonably available; therefore, uncertainty introduced by this variable is expected to be minimal.

TABLE B-4-5

COPC LOSS CONSTANT DUE TO LEACHING (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
I	Average annual irrigation	cm/yr	**0 to 100** This variable is site-specific. This range is based on information presented in U.S. EPA (1990), representing data for 69 selected cities (Baes, Sharp, Sjoreen, and Shor 1984). The 69 selected cities are not identified; however, they appear to be located throughout the continental United States. The following uncertainty is associated with this variable: To the extent that site-specific or local average annual irrigation information is not available, default values (generally based on the closest comparable location) may not accurately reflect site-specific conditions. As a result, *ksl* may be under- or overestimated to an unknown degree.
RO	Average annual surface runoff from pervious areas	cm/yr	**Varies** This variable is site-specific. According to U.S. EPA (1993), U.S. EPA (1994a), and NC DEHNR (1997), average annual surface runoff can be estimated by using the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973). According to NC DEHNR (1997), this estimate can also be made by using more detailed, site-specific procedures, such as those based on the U.S. Soil Conservation Service CNE. U.S. EPA (1985) is cited as an example of such a procedure. The following uncertainty is associated with this variable: To the extent that site-specific or local average annual surface runoff information is not available, default or estimated values may not accurately represent site-specific or local conditions. As a result, *ksl* may be under- or overestimated to an unknown degree.
E_v	Average annual evapotranspiration	cm/yr	**35 to 100** This variable is site-specific. This range is based on information presented in U. S. EPA (1990), representing data from 69 selected cities. The 69 selected cities are not identified; however, they appear to be located throughout the continental United States. The following uncertainty is associated with this variable: To the extent that site-specific or local average annual evapotranspiration information is not available, default values may not accurately reflect site-specific conditions. As a result, *ksl* may be under- or overestimated to an unknown degree.

Variable	Description	Units	Value
θ_{sw}	Soil volumetric water content	mL water/cm³ soil	**0.2** This variable is site-specific, and depends on the available water and on soil structure; if a representative watershed soil can be identified θ_{sw} can be estimated as the midpoint between a soil's field capacity and wilting point. U.S. EPA OSW recommends the use of 0.2 mL/cm³ as a default value. This value is the midpoint of the range of 0.1 (very sandy soils) to 0.3 (heavy loam/clay soils) recommended by U.S. EPA (1993) (no source or reference is provided for this range) and is consistent with other U.S. EPA (1994a) and NC DEHNR (1997). The following uncertainty is associated with this variable: The default θ_{sw} value may not accurately reflect site-specific or local conditions; therefore, *ksl* may be under- or overestimated to a small extent, based on the limited range of values.
Z_s	Soil depth mixing zone	cm	**1 to 20** U.S. EPA OSW recommends the following values for this variable: Soil / Depth (cm) / Reference Untilled / 1 / U.S. EPA (1990a) and U.S. EPA (1993a) Tilled / 20 / U.S. EPA (1990a) and U.S. EPA (1993a) U.S. EPA (1990) does not provide a reference for these values. U.S. EPA (1993a) cites U.S. EPA (1994b). Uncertainties associated with this variable include the following: (1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksr*. (2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in-situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksl*.
BD	Soil bulk density	g soil/cm³ soil	**1.5** This variable is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil (Hillel 1980), as summarized in U.S. EPA (1990). A range of 0.83 to 1.84 was originally cited in Hoffman and Baes (1979). U.S. EPA (1994) recommended a default soil bulk density value of 1.5 g/cm³, based on a mean value for loam soil from Carsel, Parrish, Jones, Hansen, and Lamb (1988). The value of 1.5 g/cm³ also represents the midpoint of the "relatively narrow range" for *BD* of 1.2 to 1.7 g/cm³ (U.S. EPA 1993). The following uncertainty is associated with this variable: The recommended soil bulk density value may not accurately represent site-specific soil conditions.

TABLE B-4-5

COPC LOSS CONSTANT DUE TO LEACHING (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
Kd_s	Soil-water partition coefficient	cm^3 water/g soil	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Uncertainties associated with this parameter will be limited if Kd_s values are calculated as described in Appendix A-3.

REFERENCES AND DISCUSSION

Baes, C.F., R.D. Sharp, A.L. Sjoreen and R.W. Shor. 1984. "A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture." Prepared for the U.S. Department of Energy under Contract No. DEAC05-840R21400.

For the continental United States, as cited in U.S. EPA (1990), this document is the source of a series of maps showing: (1) average annual precipitation (*P*), (2) average annual irrigation (*I*), and (3) average annual evapotranspiration isolines.

Carsel, R.F., R.S. Parrish, R.L. Jones, J.L. Hansen, and R.L. Lamb. 1988. "Characterizing the Uncertainty of Pesticide Leaching in Agricultural Soils." *Journal of Contaminant Hydrology.* Vol. 2. Pages 11-24.

This document is cited by U.S. EPA (1994a) as the source for a mean soil bulk density value, *BD*, of 1.5 (g soil/cm^3 soil) for loam soil.

Geraghty, J.J., D.W. Miller, F. Van der Leeden, and F.L. Troise. 1973. *Water Atlas of the United States.* Water Information Center, Port Washington, New York.

This document is cited by U.S. EPA (1993), U.S. EPA (1994a), and NC DEHNR (1997) as a reference for calculating average annual runoff, *RO.* This document provides maps with isolines of annual average surface runoff, which is defined as all flow contributions to surface water bodies, including direct runoff, shallow interflow, and ground water recharge. Because these volumes are total contributions and not only surface runoff, U.S. EPA (1994a) recommends that the volumes be reduced by 50 percent in order to estimate average annual surface runoff.

This document presents a soil bulk density, *BD*, range of 0.83 to 1.84.

Hillel, D. 1980. *Fundamentals of Soil Physics.* Academic Press, Inc. New York, New York.

This document is cited by U.S. EPA (1990) for the statement that soil bulk density, *BD*, is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil.

Hoffman, F.O., and C.F. Baes. 1979. *A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides.* ORNL/NUREG/TM-882.

This document presents a soil bulk density, *BD*, range of 0.83 to 1.84.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is one of the source documents that cites the use of the equation in Table B-4-5. However, the document is not the original source of this equation. This document also recommends the following:

- Estimation of average annual surface runoff, *RO* (cm/yr), by using the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973) or site-specific procedures, such as using the U.S. Soil Conservation Service CNE; U.S. EPA 1985 is cited as an example of such a procedure.
- A default value of 0.2 (mL water/cm^3 soil) for soil volumetric water content, θ_{sw}

COPC LOSS CONSTANT DUE TO LEACHING (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

U.S. Bureau of the Census. 1987. *Statistical Abstract of the United States:* 1987. 107th edition. Washington, D.C.

This document is a source of average annual precipitation (*P*) information for 69 selected cities, as cited in U.S. EPA (1990); these 69 cities are not identified.

U.S. EPA. 1985. *Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Groundwater.* Part I (Revised 1985). Environmental Research Laboratory. Athens, Georgia. EPA/600/6-85/002a. September.

This document is cited by NC DEHNR (1997) as an example of the use of the U.S. Soil Conservation Service CNE to estimate *RO.*

U.S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600-90-003. January.

This document presents ranges of (1) average annual precipitation, (2) average annual irrigation, and (3) average annual evapotranspiration. This document cites Baes, Sharp, Sjoreen, and Shor (1984) and U.S. Bureau of the Census (1987) as the original sources of this information.

U.S. EPA. 1993. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, D.C. November.

This document is one of the reference sources for the equation in Table B-4-5; this document also recommends the following:

- A range of soil volumetric water content, θ_{sw}, values of 0.1 (very sandy soils) to 0.3 (heavy loam/clay soils); the original source or reference for these values is not identified.
- A range of values for soil mixing depth, Z_s, for tilled and untilled soil; the original source reference for these values is not identified.
- A range (2 to 280,000 [mL water/g soil]) of Kd_s values for inorganic COPCs
- A "relatively narrow range" for soil bulk density, *BD*, of 1.2 to 1.7 (g soil/cm^3 soil)

This document is one of the reference source documents for the equation in Table B-4-5. The original source of this equation is not identified. This document also presents a range of values for soil mixing depth, *Z*, for tilled and untilled soil; the original source of these values is not identified. Finally, this document presents several COPC-specific Kd_s values that were used to establish a range (2 to 280,000 mL/g) of Kd_s values.

U.S. EPA. 1994a. *Revised Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

U.S. EPA. 1994b. *Estimating Exposure to Dioxin-Like Compounds. Volulme III: Site-specific Assessment Procedures.* External Review Draft. Office of Research and Development. Washington, D.C. EPA/600/6-88/005Cc. June.

This document presents values for soil mixing depth, Z_s, for tilled and untilled soil, as cited in U.S. EPA (1993).

This document recommends (1) a default soil volumetric water content, θ_{sw}, value of 0.2 (mL water/cm^3 soil), based on U.S. EPA (1993), and (2) a default soil bulk density, *BD*, value of 1.5 (g soil/cm^3 soil), based on a mean value for loam soil from Carsel, Parrish, Jones, Hansen, and Lamb (1988).

TABLE B-4-6

COPC LOSS CONSTANT DUE TO VOLATILIZATION (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Description

This equation calculates the COPC loss constant from soil due to volatilization. Consistent with U.S. EPA guidance (1994) and based on the need for additional research to be conducted to determine the magnitude of the uncertainty introduced for modeling volatile COPCs from soil, U.S. EPA OSW recommends that, until identification and validation of more applicable models, the constant for the loss of soil resulting from volatilization *(ksv)* should be set equal to zero. In cases where high concentrations of volatile organic compounds are expected to be present in the soil and the permitting authority considers calculation of *ksv* to be appropriate, the equation presented in this table should be considered. U.S. EPA OSW also recommends consulting the methodologies described in U.S. EPA NCEA document, *Methodology for Assessing Health Risks Associated with Multiple Exposure Pathways to Combustor Emissions* (In Press). Uncertainties associated with this equation include the following:

(1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksv*.

(2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksv*.

Equation

$$ksv = \left[\frac{3.1536 \cdot 10^{7} \cdot H}{Z_s \cdot Kd_s \cdot R \cdot T_a \cdot BD}\right] \cdot \left[0.482 \cdot W^{0.78} \cdot \left(\frac{\mu_a}{\rho_a \cdot D_a}\right)^{-0.67} \cdot \left(\sqrt{\frac{4A}{\pi}}\right)^{-0.11}\right]$$

Variable	Definition	Units	Value
ksv	Constant for COPC loss due to volatilization	yr^{1}	**0** Consistent with U.S. EPA guidance (1994) and based on the need for additional research to be conducted to determine the magnitude of the uncertainty introduced for modeling volatile COPCs from soil, U.S. EPA OSW recommends that, until identification and validation of more applicable models, the constant for the loss of soil resulting from volatilization (*ksv*) should be set equal to zero.
0.482	Empirical constant	unitless	This is an empirical constant calculated during the development of this equation.
0.78	Empirical constant	unitless	This is an empirical constant calculated during the development of this equation.
-0.67	Empirical constant	unitless	This is an empirical constant calculated during the development of this equation.
-0.11	Empirical constant	unitless	This is an empirical constant calculated during the development of this equation.
$3.1536 \times 10^{+07}$	Units conversion factor	s/yr	

TABLE B-4-6

COPC LOSS CONSTANT DUE TO VOLATILIZATION (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Definition	Units	Value
H	Henry's Law constant	atm-m^3/mol	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Values for this variable, estimated by using the parameters and algorithms in Appendix A-3, may under- or overestimate the actual COPC-specific values. As a result, *ksv* may be under- or overestimated.
Z_s	Soil mixing zone depth	cm	**1 to 20** U.S. EPA OSW recommends the following values for this variable: <u>Soil</u> — <u>Depth (cm)</u> — <u>Reference</u> Untilled — 1 — U.S. EPA (1990a) and U.S. EPA (1993a) Tilled — 20 — U.S. EPA (1990a) and U.S. EPA (1993a) U.S. EPA (1990) does not provide a reference for these values. U.S. EPA (1993a) cites U.S. EPA (1994a). Uncertainties associated with this variable include the following: (1) For soluble COPCs, leaching might lead to movement to below 1 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksr*. (2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) in comparison to that of other residues. This uncertainty may underestimate *ksv*.
Kd_s	Soil-water partition coefficient	cm^3 water/g soil	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Uncertainties associated with this parameter will be limited if Kd_s values are calculated as described in Appendix A-3.
R	Universal gas constant	atm-m^3/mol-K	**8.205×10^{-5}** There are no uncertainties associated with this parameter.

TABLE B-4-6

COPC LOSS CONSTANT DUE TO VOLATILIZATION (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Definition	Units	Value
T_a	Ambient air temperature	K	**298** This variable is site-specific. U.S. EPA (1990) also recommends an ambient air temperature of 298 K. The following uncertainty is associated with this variable: To the extent that site-specific or local values for the variable are not available, default values may not accurately represent site-specific conditions. The uncertainty associated with the selection of a single value from within the temperature range at a single location is expected to be more significant than the uncertainty associated with choosing a single ambient temperature to represent all localities. In other words, the range of average ambient temperatures across the country is generally less than the temperature range at an individual site.
BD	Soil bulk density	g soil/cm^3 soil	**1.5** This variable is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil (Hillel 1980), as summarized in U.S. EPA (1990). A rangeof 0.83 to 1.84 was originally cited in Hoffman and Baes (1979). U.S. EPA (1994b) recommended a default soil bulk density value of 1.5 g/cm^3, based on a mean value for loam soil from Carsel, Parrish, Jones, Hansen, and Lamb (1988). The value of 1.5 g/cm^3 also represents the midpoint of the "relatively narrow range" for *BD* of 1.2 to 1.7 g/cm^3 (U.S. EPA 1993). The following uncertainty is associated with this variable: The recommended soil bulk density value may not accurately represent site-specific soil conditions.
W	Average annual wind speed	m/s	**3.9** Consistent with U.S. EPA (1990), U.S. EPA OSW recommends a default value of 3.9 m/s. See Chapter 3 for guidance regarding the references and methods used to determine a site-specific value that isconsistent with air dispersion modeling. The following uncertainty is associated with this variable: To the extent that site-specific or local values for this variable are not available, default values may not accurately represent site-specific conditions. The uncertainty associated with the selection of a single value from within the range of windspeeds at a single location may be more significant than the uncertainty associated with choosing a single windspeed to represent all locations.

Variable	Definition	Units	Value
μ_a	Viscosity of air	g/cm-s	**1.81 x 10^{-04}** U.S. EPA OSW recommends the use of this value, based on Weast (1980). This value applies at standard conditions (25 °C or 298 K and 1 atm or 760 mm Hg). The viscosity of air may vary slightly with temperature.
ρ_a	Density of air	g/cm^3	**0.0012** U.S. EPA OSW recommends the use of this value, based on Weast (1980). This value applies at standard conditions (25°C or 298 K and 1 atm or 760 mm Hg). The density of air will vary with temperature.
D_a	Diffusivity of COPC in air	cm^2/s	**Varies** This value is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: The default D_a values may not accurately represent the behavior of COPCs under site-specific conditions. However, the degree of uncertainty is expected to be minimal.
A	Surface area of contaminated area.	m^2	**1.0** See Chapter 5 of the HHRAP for guidance regarding the calculation of this value.

REFERENCES AND DISCUSSION

Carsel, R.F., R.S, Parrish, R.L. Jones, J.L. Hansen, and R.L. Lamb. 1988. "Characterizing the Uncertainty of Pesticide Leaching in Agricultural Soils." *Journal of Contaminant Hydrology.* Vol. 2. Pages 11-24.

This document is cited by U.S. EPA (1994b) as the source of a mean soil bulk density value, *BD*, of 1.5 (g soil/cm^3 soil) for loam soil.

Hillel, D. 1980. *Fundamentals of Soil Physics.* Academic Press, Inc. New York, New York.

Hoffman, F.O., and C.F. Baes. 1979. *A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides.* ORNL/NUREG/TM-882.

This document presents a soil bulk density, *BD*, range of 0.83 to 1.84.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is one of the source documents that cites the use of the equation in Table B-4-6; however, the original source of this equation is not identified.

U. S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600-90-003. January.

This document recommends the following:

- A range of values for soil mixing zone depth, Z_s, for tilled and untilled soil; however, the source or basis for these values is not identified
- A default ambient air temperature of 298 K
- An average annual wind speed of 3.9 m/s; however, no source or reference for this value is identified.

U.S. EPA. 1993. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, D.C. November.

This document is one of the reference source documents for the equation in Table B-4-6; however, the original reference for this equation is not identified.

This document also presents the following:

- A range of values for soil mixing depth, Z_s, for tilled and untilled soil; however, the original source of these values is not identified.
- COPC-specific Kd_s values that were used to establish a range (2 to 280,000 [mL water/g soil]) of Kd_s values for inorganic COPCs
- A "relatively narrow range" for soil bulk density, *BD*, of 1.2 to 1.7 (g soil/cm^3 soil)

U.S. EPA. 1994. *Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* April 15.

U.S. EPA. 1994a. *Estimating Exposure to Dioxin-Like Compounds. Volume III: Site-specific Assessment Procedures.* External Review Draft. Office of Research and Development. Washington, D.C. EPA/600/6-88/005Cc. June.

This document presents value for soil, mixing depth, Z_s, for tilled and untilled soil as cited in U.S. EPA (1993).

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Waste. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document recommends a default soil density, *BD*, value of 1.5 (g soil/cm^3 soil), based on a mean value for loam soil that is taken from Carsel, Parrish, Jones, Hansen, and Lamb (1988).

Weast, R.C. 1980. *Handbook of Chemistry and Physics*. 61st Edition. CRC Press, Inc. Cleveland, Ohio.

This document is cited by NC DEHNR (1997) as the source recommended values for viscosity of air, μ_a, and density of air, ρ_a.

TABLE B-4-7

TOTAL WATER BODY LOAD
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Description

This equation calculates the total average water body load from wet and dry vapor and particle deposition, runoff, and erosion loads. The limitations and uncertainties incorporated by using this equation include the following:

(1) Uncertainties associated with variables in equations presented in Tables B-4-8, B-4-9, B-4-10, B-4-11, and B-4-12 that are site-specific. These variables include *Q, Dywwv, Dytwp,* A_w, *Cywv*, A_I, A_L, *Cs*, and X_e. Values for many of these variables are estimated through the use of mathematical models and the uncertainties associated with values for these variables may be significant in some cases (Bidleman 1988).

(2) Uncertainties associated with the remaining variables in equations presented in Tables B-4-8, B-4-9, B-4-10, B-4-11, and B-4-12 are expected to be less significant, primarily because of the narrow ranges of probable values for these variables or because values for these variables (such as Kd_s) were estimated by using well-established estimation methods.

Equation

$$L_T = L_{DEP} + L_{dif} + L_{RI} + L_R + L_E$$

Variable	Description	Units	Value
L_T	Total COPC load to the water body	g/yr	
L_{DEP}	Total (wet and dry) particle phase and wet vapor phase COPC direct deposition load to water body	g/yr	**Varies** This variable is COPC- and site-specific, and is calculated by using equation presented in Table B-4-8. Uncertainty associated with this variable include the following: Most of the uncertainty associated with the variables in the equation in Table B-4-8, specifically those associated with *Q, Dywwv, Dytwp*, and A_w, are site-specific and may be significant in some cases.
L_{dif}	Vapor phase COPC diffusion (dry deposition) load to water body	g/yr	**Varies** This variable is calculated by using equation presented in Table B-4-12. Uncertainty associated with this variable include the following: Most of the uncertainty associated with the variables in the equation in Table B-4-12, specifically those associated with *Q, Cywv*, and A_w, are site-specific.

TABLE B-4-7

TOTAL WATER BODY LOAD
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
L_{RI}	Runoff load from impervious surfaces	g/yr	**Varies** This variable is calculated by using the equation presented in Table B-4-9. Uncertainty associated with this variable include the following: Most of the uncertainty associated with the variables in this equation, specifically those associated with *Q*, *Dywwv*, *Dytwp*, and A_I, are site-specific.
L_R	Runoff load from pervious surfaces	g/yr	**Varies** This variable is calculated by using equation presented in Table B-4-10. Uncertainties associated with this variable include the following: (1) Most of the uncertainties associated with the variables in the equation in Table B-4-10, specifically those for A_L, A_I, and *Cs*, are site-specific. (2) Uncertainties associated with the remaining variable in the equation in Table B-4-10 are not expected to be significant, primarily because of the narrow ranges of probable values for these variables or the use of well-established estimation procedures (Kd_s).
L_E	Soil erosion load	g/yr	**Varies** This variable is calculated by using equation presented in Table B-4-11. Uncertainties associated with this variable include the following: (1) Most of the uncertainties associated with the variables in the equation in Table B-4-11, specifically those for X_e, A_L, A_I, and Cs, are site-specific. (2) Uncertainties associated with the remaining variables in the equation in Table B-4-11 are not expected to be significant, primarily because of the narrow range of probable values for these variables or the use of well-established estimation procedures (Kd_s).

TABLE B-4-7

TOTAL WATER BODY LOAD
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

REFERENCES AND DISCUSSION

Bidleman, T.F. 1988. "Atmospheric Processes." *Environmental Science and Technology.* Volume 22. Number 4. Pages 361-367.

For discussion, see References and Discussion in Table B-1-1.

TABLE B-4-8

DEPOSITION TO WATER BODY
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Description

This equation calculates the average load to the water body from direct deposition of wet and dry particles and wet vapors onto the surface of the water body. Uncertainties associated with this equation include the following:

(1) Most of the uncertainties associated with the variables in this equation, specifically those associated with Q, $Dywwv$, $Dytwp$, and A_w, are site-specific.

(2) It is calculated on the basis of the assumption of a default S_T value for background plus local sources, rather than an S_T value for urban sources. If a specific site is located in an urban area, the use of the latter S_T value may be more appropriate. Specifically, the S_T value for urban sources is about one order of magnitude greater than that for background plus local sources and would result in a lower calculated F_v value; however, the F_v value is likely to be only a few percent lower.

Equation

$$L_{DEP} = Q \cdot [\, F_v \cdot Dywwv + (1 - F_v) \cdot Dytwp] \cdot A_w$$

For mercury modeling

$$L_{DEP} = 0.48Q \cdot [\, F_v \cdot Dywwv + (1 - F_v) \cdot Dytwp] \cdot A_w$$

Deposition to water body is calculated using 0.48Q and $F_v = 0.85$ for divalent mercury. Use $F_v = 0.85$ for the mercury modeling to calculate L_{DEP}. The calculated L_{DEP} value is split into the divalent and methyl mercury forms based on the 85% divalent mercury (Hg^{2+}) and 15% methyl mercury (MHg) speciation split.

$$L_{DEP}(Hg^{2+}) = 0.85\ L_{DEP}$$
$$L_{DEP}(MHg) = 0.15\ L_{DEP}$$

Variable	Description	Units	Value
L_{DEP}	Total (wet and dry) particle phase and wet vapor phase direct deposition load to water body	g/yr	
Q	COPC-specific emission rate	g/s	**Varies** This variable is COPC- and site-specific. See Chapters 2 and 3 for guidance regarding the calculation of this variable. Uncertainties associated with this variable are site-specific.

TABLE B-4-8

DEPOSITION TO WATER BODY (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
F_v	Fraction of COPC air concentration in vapor phase	unitless	**0 to 1** This variable is COPC-specific. Discussion of this variable and COPC-specific values is presented in Appendix A-3. This range is based on values presented in Appendix A-3. Values are also presented in U.S. EPA (1994b) and NC DEHNR (1997). F_v was calculated using an equation presented in Junge (1977) for all organic COPCs, including PCDDs and PCDFs. U.S. EPA (1994c) states that $F_v = 0$ for all metals (except mercury). The following uncertainties are associated with this variable: (1) It is based on the assumption of a default S_T value for background plus local sources, rather than an S_T value for urban sources. If a specific site is located in an urban area, the use of the latter S_T value may be more appropriate. Specifically, the S_T value for urban sources is about one order of magnitude greater than that for background plus local sources, and it would result in a lower calculated F_v value; however, the F_v value is likely to be only a few percent lower. (2) According to Bidleman (1988), the equation used to calculate F_v assumes that the variable c (Junge constant) is constant for all chemicals; however, the value of c depends on the chemical (sorbate) molecular weight, the surface concentration for monolayer coverage, and the difference between the heat of desorption from the particle surface and the heat of vaporization of the liquid-phase sorbate. To the extent that site- or COPC-specific conditions may cause the value of c to vary, uncertainty is introduced if a constant value of c is used to calculate F_v.
Dywwv	Unitized yearly (water body or watershed) average wet deposition from particle phase	s/m^2-yr	**Varies** This variable is COPC- and site-specific, and is determined by air dispersion modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.
Dytwp	Unitized yearly (water body or watershed) average total (wet and dry) deposition from vapor phase	s/m^2-yr	**Varies** This variable is COPC- and site-specific, and is determined by air dispersion modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.
A_w	Water body surface area	m^2	**Varies** This variable is COPC- and site-specific, and is determined by air dispersion modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.

DEPOSITION TO WATER BODY
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

REFERENCES AND DISCUSSION

Bidleman, T.F. 1988. "Atmospheric Processes." *Environmental Science and Technology.* Volume 22. Number 4. Pages 361-367.

For discussion, see References and Discussion in Table B-1-1.

Junge, C.E. 1977. *Fate of Pollutants in Air and Water Environments, Part I.* Suffet, I.H., Ed. Wiley. New York. Pages 7-26.

NC DEHNR. 1997. *Final NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is a reference source for the equation in Table B-4-8. This document also recommends by using the equations in Bidleman (1988) to calculate F_v values for all organics other than dioxins (PCDD/PCDFs). However, the document does not present a recommendation for dioxins. Finally, this document states that metals are generally entirely in the particulate phase ($F_v = 0$) except for mercury, which is assumed to be entirely in the vapor phase. The document does not state whether F_v for mercury should be calculated by using the equations in Bidleman (1988).

U.S. EPA. 1994. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document is a reference source for Equation B-4-8. This document also presents values for organic COPCs that range from 0.27 to 1. F_v values for organics other than PCDD/PCDFs are calculated by using the equations presented in Bidleman (1988). The F_v value for PCDD/PCDFs is assumed to be 0.27, based on U.S. EPA (no date). Finally, this document presents F_v values for inorganic COPCs equal to 0, based on the assumption that these COPCs are nonvolatile and assumed to be 100 percent in the particulate phase and 0 percent in the vapor phase.

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

TABLE B-4-9

IMPERVIOUS RUNOFF LOAD TO WATER BODY
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Description

This equation calculates the average runoff load to the water body from impervious surfaces in the watershed from which runoff is conveyed directly to the water body.

Uncertainties associated with this equation include the following:

(1) Most of the uncertainties associated with the variables in this equation, specifically those associated with Q, $Dywwv$, $Dytwp$, and A_I, are site-specific.

(2) The equation assumes a default S_T value for background plus local sources, rather than an S_T value for urban sources. If a specific site is located in an urban area, the use of the latter S_T value may be more appropriate. Specifically, the S_T value for urban sources is about one order of magnitude greater than that for background plus local sources and would result in a lower calculated F_v value; however, the F_v value is likely to be only a few percent lower.

Equation

$$L_{RI} = Q \cdot \left[F_v \cdot Dywwv + (1.0 - F_v) \cdot Dytwp \right] \cdot A_I$$

For mercury modeling

$$L_{RI} = 0.48Q \cdot \left[F_v \cdot Dywwv + (1.0 - F_v) \cdot Dytwp \right] \cdot A_I$$

Impervious runoff load to water body is calculated using $0.48Q$ and $F_v = 0.85$ for divalent mercury. Use $F_v = 0.85$ for the mercury modeling to calculate L_{RI}. The calculated L_{RI} value is split into the divalent and methyl mercury forms based on the 85% divalent mercury (Hg^{2+}) and 15% methyl mercury (MHg) speciation split.

$$L_{RI}(Hg^{2+}) = 0.85\, L_{RI}$$
$$L_{RI}(MHg) = 0.15\, L_{RI}$$

Variable	Description	Units	Value
L_{RI}	Runoff load from impervious surfaces	g/yr	
Q	COPC-specific emission rate	g/s	**Varies** This variable is COPC- and site-specific (see Chapters 2 and 3). Uncertainties associated with this variable are site-specific.

TABLE B-4-9

IMPERVIOUS RUNOFF LOAD TO WATER BODY
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
F_v	Fraction of COPC air concentration in vapor phase	unitless	**0 to 1** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values is presented in Appendix A-3. This range is based on values presented in Appendix A-3. Values are also presented in U.S. EPA (1994b) and NC DEHNR (1997). F_v was calculated using an equation presented in Junge (1977) for all organic COPCs, including PCDDs and PCDFs. U.S. EPA (1994c) states that $F_v = 0$ for all metals (except mercury). The following uncertainties are associated with this variable: (1) It is based on the assumption of a default S_T value for background plus local sources, rather than an S_T value for urban sources. If a specific site is located in an urban area, the use of the latter S_T value may be more appropriate. Specifically, the S_T value for urban sources is about one order of magnitude greater than that for background plus local sources, and it would result in a lower calculated F_v value; however, the F_v value is likely to be only a few percent lower. (2) According to Bidleman (1988), the equation used to calculate F_v assumes that the variable *c* (Junge constant) is constant for all chemicals; however, the value of *c* depends on the chemical (sorbate) molecular weight, the surface concentration for monolayer coverage, and the difference between the heat of desorption from the particle surface and the heat of vaporization of the liquid-phase sorbate. To the extent that site- or COPC-specific conditions may cause the value of *c* to vary, uncertainty is introduced if a constant value of *c* is used to calculate F_v.
Dywwv	Unitized yearly (water body or watershed) average wet deposition from vapor phase	s/m^2-yr	**Varies** This variable is COPC- and site-specific, and is determined by air dispersion modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.
Dytwp	Unitized yearly (water body or watershed) average total (wet and dry) deposition from particle phase	s/m^2-yr	**Varies** This variable is COPC- and site-specific, and is determined by air dispersion modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.
A_I	Impervious watershed area receiving COPC deposition	m^2	**Varies** This variable is site-specific. Uncertainties associated with this variable are site-specific.

TABLE B-4-9

IMPERVIOUS RUNOFF LOAD TO WATER BODY (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

REFERENCES AND DISCUSSION

Bidleman, T.F. 1988. "Atmospheric Processes." *Environmental Science and Technology.* Volume 22 Number 4. Pages 361-367.

For discussion see References and Discussion in Table B-1-1.

Junge, C.E. 1977. *Fate of Pollutants in Air and Water Environments, Part I.* Suffet, I.H., Ed. Wiley. New York. Pages 7-26.

NC DEHNR. 1997. *Final NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is a reference source for the equation in Table B-4-9. This document also recommends using the equations in Bidleman (1988) to calculate F_v values for all organics other than dioxins (PCDD/PCDFs). However, the document does not present a recommendation for dioxins. Finally, this document states that metals are generally entirely in the particulate phase ($F_v = 0$) except for mercury, which is assumed to be entirely in the vapor phase. The document does not state whether F_v for mercury should be calculated by using the equations in Bidleman (1988).

U.S. EPA. 1994. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document is a reference source for the equation in Table B-4-9. This document also presents values for organic COPCs that range form 0.27 to 1. F_v values for organics other than PCDD/PCDFs are calculated by using the equations presented in Bidleman (1988). The F_v value for PCDD/PCDFs is assumed to be 0.27, based on Lorber (no date). Finally, this document presents F_v values for inorganic COPCs equal to 0, based on the assumption that these COPCs are nonvolatile and assumed to be 100 percent in the particle phase and 0 percent in the vapor phase.

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

TABLE B-4-10

PERVIOUS RUNOFF LOAD TO WATER BODY (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Description

This equation calculates the average runoff load to the water body from pervious soil surfaces in the watershed. Uncertainty associated with this equation includes the following:

> To the extent that site-specific or local average annual surface runoff information is not available, default or estimated values may not accurately represent site-specific or local conditions. As a result, L_R may be under- or overestimated to an unknown degree.

Equation

$$L_R = RO \cdot (A_L - A_I) \cdot \frac{Cs \cdot BD}{\theta_{sw} + Kd_s \cdot BD} \cdot 0.01$$

For mercury modeling, the runoff load to water body from pervious surfaces is calculated for divalent mercury (Hg^{2+}) and methyl mercury (MHg) using their respective *Cs* values and Kd_s values.

Variable	Description	Units	Value
L_R	Runoff load from pervious surfaces	g/yr	
RO	Average annual surface runoff from pervious areas	cm/yr	**Varies** This variable is site-specific. According to U.S. EPA (1993), U.S. EPA (1994), and NC DEHNR (1997), average annual surface runoff, *RO*, can be estimated by using the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973). According to NC DEHNR (1997), more detailed, site-specific procedures for estimating the amount of surface runoff, such as those based on the U.S. Soil Conservation Service CNE may also be used. U.S. EPA (1985) is cited as an example of such a procedure. The following uncertainty is associated with this variable: To the extent that site-specific or local average annual surface runoff information is not available, default or estimated values may not accurately represent site-specific or local conditions. As a result, *RO* may be under- or overestimated to an unknown degree.
A_L	Total watershed area receiving COPC deposition	m^2	**Varies** This variable is site-specific. See Chapter 4 for procedures to calculate this variable. Uncertainties associated with this variable are site-specific.

Variable	Description	Units	Value
A_I	Impervious watershed area receiving COPC deposition	m^2	**Varies** This variable is site-specific. See Chapter 4 for procedures to calculate this variable. Uncertainties associated with this variable are site-specific.
Cs	Average soil concentration over exposure duration	mg COPC/kg soil	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation presented in Table B-4-1. Uncertaintiesassociated with this variable are site-specific.
BD	Soil bulk density	g soil/cm^3 soil	**1.5** This variable is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil (Hillel 1980), as summarized in U.S. EPA (1990). A range of 0.83 to 1.84 was originally cited in Hoffman and Baes (1979). U.S. EPA (1994b) recommended a default soil bulk density value of 1.5 g/cm^3, based on a mean value for loam soil from Carsel, Parrish, Jones, Hansen, and Lamb (1988). The value of 1.5 g/cm^3 also represents the midpoint of the "relatively narrow range" for *BD* of 1.2 to 1.7 g/cm^3. The following uncertainty is associated with this variable: The recommended range of soil bulk density values may not accurately represent site-specific soil conditions.
θ_{sw}	Soil volumetric water content	mL water/cm^3 soil	**0.2** This variable depends on the available water and on soil structure; θ_{sw} can be estimated as the midpoint between a soil's field capacity and wilting point, if a representative watershed soil can be identified. However, U.S. EPA OSW recommends the use of 0.2 mL/cm^3 as a default value; this value is the midpoint of the range 0.1 (very sandy soils) to 0.3 (heavy loam/clay soils) recommended by U.S. EPA (1993) (no source or reference is provided for this range) and is consistent with other U.S. EPA (1994b) and NC DEHNR (1997) guidance. The following uncertainty is associated with this variable: The default θ_{sw} value may not accurately reflect site-specific or local conditions; therefore, K_R may be under- or overestimated to a limited extent.

TABLE B-4-10

PERVIOUS RUNOFF LOAD TO WATER BODY
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
Kd_s	Soil-water partition coefficient	cm^3 water/g soil	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Uncertainties associated with this parameter will be limited if Kd_s values are calculated as described in Appendix A-3.
0.01	Units conversion factor	kg-cm^2/mg-m^2	

TABLE B-4-10

PERVIOUS RUNOFF LOAD TO WATER BODY (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

REFERENCES AND DISCUSSION

Carsel, R.F., R.S. Parrish, R.L. Jones, J.L. Hansen, and R.L. Lamb. 1988. "Characterizing the Uncertainty of Pesticide Leaching in Agricultural Soils." *Journal of Contaminant Hydrology.* Volume 2: pages 11-24.

Geraghty, J.J., D.W Miller, F. Van der Leeden, and F.L. Troise. 1973. *Water Atlas of the United States.* Water Information Center. Port Washington, New York.

This document is cited by U.S. EPA (1993), U.S. EPA (1994c), and NC DEHNR (1997) as a reference for calculating average annual runoff, *RO*. Specifically, this reference provides maps with isolines of annual average surface water runoff, which is defined as all flow contributions to surface water bodies, including direct runoff, shallow interflow, and ground water recharge. Because these volumes are total contributions and not only surface runoff, U.S. EPA (1994c) notes that they need to be reduced to estimate surface runoff. U.S. EPA (1994c) recommends a reduction of 50 percent.

Hillel, D. 1980. *Fundamentals of Soil Physics.* Academic Pres, Inc. New York.

This document is cited by U.S. EPA (1990) for the statement that soil bulk density, *BD*, is affected by soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil.

Hoffman, F.O., and C.F. Baes. 1979. *A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides.* ORNL/NUREG/TM-882.

This document presents a soil bulk density, *BD*, range of 0.83 to 1.84 (g soil/cm^3 soil).

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is one of the source documented that cites the use of the equation in Table B-4-10; however, the document is not the original source of this equation. This document also recommends the following:

- Estimation of average annual runoff, *RO* (cm/yr), by using the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973) or site-specific procedures, such as the U.S. Soil Conservation Service CNE; U.S. EPA (1985) is cited as an example of the use of the CNE
- A default value of 0.2 (mL water/cm^3 soil) for soil volumetric content (θ_{sw})

U.S. EPA. 1985. *Water Quality Assessment: A Screening Procedures for Toxic and Conventional Pollutants in Surface and Ground Water - Part I (Revised - 1985).* Environmental Research Laboratory. Athens, Georgia. EPA/600/6-85/002a. September.

U.S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600-90-003. January.

This document cites Hillel (1980) for the statement that only soil bulk density, *BD*, is affected by the soil structure, such as loosened or compaction of the soil, depending on the water and clay content of the soil.

TABLE B-4-10

PERVIOUS RUNOFF LOAD TO WATER BODY (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

U.S. EPA. 1993. *Addendum: Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Working Group Recommendations. Office of Solid Waste and Office of Research and Development. Washington, D.C. September 24.

This document is a source of COPC-specific (inorganics only) Kd_s values used to develop a range (2 to 280,000 [mL water/g soil]) of Kd_s values. This document also recommends a range of soil volumetric water content (θ_{sw}) of 0.1 (mL water/cm^3 soil) (very sandy soils) to 0.3 mL water/cm^3 soil)(heavy loam/clay soils); however, no source or reference is provided for this range.

U.S. EPA. 1994. *Revised Draft Guidance of Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes.* Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities. Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document recommends (1) a default soil bulk density value of 1.5 (g soil/cm^3 soil), based on a mean value for loam soil from Carsel, Parrish, Jones, Hansen, and Lamb (1988), and (2) a default soil volumetric water content, θ_{sw}, value of 0.2 (mL water/cm^3 soil), based on U.S. EPA (1993).

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

TABLE B-4-11

EROSION LOAD TO WATER BODY
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Description

This equation calculates the load to the water body from soil erosion. Uncertainties associated with this equation include the following:

(1) Most of the uncertainties associated with the variables in the equation in Table B-4-11, specifically those for X_e, A_S, A_I, and Cs, are site-specific and may be significant in some cases.
(2) Uncertainties associated with the remaining variables in the equation in Table B-4-11 are not expected to be significant, primarily because of the narrow ranges of probable values for these variables or the use of well-established estimation procedures (Kd_s).

Equation

$$L_E = X_e \cdot (A_L - A_I) \cdot SD \cdot ER \cdot \frac{Cs \cdot Kd_s \cdot BD}{\theta_{sw} + Kd_s \cdot BD} \cdot 0.001$$

Variable	Description	Units	Value
L_E	Soil erosion load	g/yr	
X_e	Unit soil loss	kg/m^2-yr	**Varies** This variable is site-specific, and is calculated by using the equation presented in Table B-4-13. The following uncertainty is associated with this variable: All of the equation variables are site-specific. Use of default values rather than site-specific values, for any or all or these variables, will result in estimates of unit soil loss, X_e, that are under- or overestimated to some degree. The range of X_e calculated on the basis of default values spans slightly more than one order of magnitude (0.6 to 36.3 kg/m^2-yr).
A_L	Total watershed area receiving deposition	m^2	**Varies** This variable is site-specific (see Chapter 4). Uncertainties associated with this variable are site-specific.
A_I	Area of impervious watershed receiving deposition	m^2	**Varies** This variable is site-specific (see Chapter 4). Uncertainties associated with this variable are site-specific.

EROSION LOAD TO WATER BODY (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
SD	Watershed sediment delivery ratio	unitless	**Varies** This value is site-specific and is calculated by using equation in Table B-4-14. The following uncertainty is associated with this variable: The recommended default values for the variables *a* and *b* (empirical intercept coefficient and empirical slope coefficient, respectively) are average values, based on a review of sediment yields from various watersheds. These default values may not accurately represent site-specific watershed conditions and, therefore, may contribute to the under- or over estimation of L_E.
ER	Soil enrichment ratio	unitless	**1 or 3** COPC enrichment occurs because (1) lighter soil particles erode more than heavier soil particles and (2) concentrations of organic COPCs—which is a function of organic carbon content of sorbing media—are expected to be higher in eroded material than *in situ* soil (U.S. EPA 1993). In the absence of site-specific data, U.S. EPA OSW recommends a default value of 3 for organic COPCs and 1 for inorganic COPCs. This is consistent with other U.S. EPA guidance (1993), which recommends a range of 1 to 5 and a value of 3 as a "reasonable first estimate". This range has been used for organic matter, phosphorus, and other soil-bound COPCs (U.S. EPA 1993); however, no sources or references were provided for this range. *ER* is generally higher in sandy soils than in silty or loamy soils (U.S. EPA 1993). The following uncertainty is associated with this variable: The default *ER* value may not accurately reflect site-specific conditions; therefore, L_E may be over- or underestimated to an unknown, but relatively small, extent. The extent of any uncertainties will be reduced by using county-specific *ER* values.
Cs	Average soil concentration over exposure duration	mg COPC/kg soil	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-4-1. Uncertainties are site-specific.
Kd_s	Soil-water partition coefficient	mL water/g soil (or cm^3 water/g soil)	**Varies** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Uncertainties associated with this parameter will be limited if Kd_s values are calculated as described in Appendix A-3.

TABLE B-4-11

EROSION LOAD TO WATER BODY
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
BD	Soil bulk density	g/cm^3	**1.5** This variable is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil (Hillel 1980), as summarized in U.S. EPA (1990). A range of 0.83 to 1.84 was originally cited in Hoffman and Baes (1979). U.S. EPA (1994a) recommended a default soil bulk density value of 1.5 g/cm^3, based on a mean value for loam soil from Carsel, Parrish, Jones, Hansen, and Lamb (1988). The value of 1.5 g/cm^3 also represents the midpoint of the "relatively narrow range" for *BD* of 1.2 to 1.7 g/cm^3. The following uncertainty is associated with this variable: The recommended soil bulk density value may not accurately represent site-specific soil conditions; and may under- or overestimate site-specific soil conditions to an unknown degree.
θ_{sw}	Soil volumetric water content	mL water/cm^3 soil	**0.2** This variable is site-specific, and depends on the available water and on soil structure. θ_{sw} can be estimated as the midpoint between a soil's field capacity and wilting point, if a representative watershed soil can be identified. However, U.S. EPA OSW recommends the use of 0.2 mL/cm^3 as a default value. This value is the midpoint of the range of 0.1 (very sandy soils), to 0.3 (heavy loam/clay soils), recommended by U.S. EPA (1993) (no source or reference is provided for this range) and is consistent with U.S. EPA (1994) and NC DEHNR (1997). The following uncertainty is associated with this variable: The default θ_{sw} value may not accurately reflect site-specific or local conditions; therefore, L_E may be under- or overestimated to a small extent, based on the limited range of values.
0.001	Units conversion factor	kg-cm^2/mg-m^2	

REFERENCES AND DISCUSSION

Carsel, R.F., R.S. Parrish, R.L. Jones, J.L. Hansen, and R.L. Lamb. 1988. "Characterizing the Uncertainty of Pesticide Leaching in Agricultural Soils." *Journal of Contaminant Hydrology.* Volume 2. Pages 11-24.

This document is the source for a mean soil bulk density, *BD*, of 1.5 (g soil/cm^3 soil) for loam soil.

Hillel, D. 1980. *Fundamentals of Soil Physics.* Academic Press, Inc. New York.

This document is cited by U.S. EPA (1990) for the statement that soil bulk density, *BD*, is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil.

Hoffman, F.O., and C.F. Baes. 1979. *A Statistical Analysis of Selected Parameters for Predicting Food Chain Transport and Internal Dose of Radionuclides.* ORNL/NUREG/TM-882.

This document presents a soil bulk density, *BD*, range of 0.83 to 1.84 (g soil/cm^3 soil).

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is cited as one of the sources for the range of *BD* values, and the default value for the volumetric soil water content.

U.S. EPA. 1990. *Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Environmental Criteria and Assessment Office. Office of Research and Development. EPA 600-90-003. January.

This document cites Hillel (1980) for the statement that soil bulk density, *BD*, is affected by the soil structure, such as looseness or compaction of the soil, depending on the water and clay content of the soil.

U.S. EPA. 1993. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, D.C. November 1993.

This document is the source of the recommended range of COPC enrichment ratio, *ER*, values. This range, 1 to 5, has been used for organic matter, phosphorous, and other soil-based COPCs. This document recommends a value of 3 as a "reasonable first estimate," and states that COPC enrichment occurs because lighter soil particles erode more than heavier soil particles. Lighter soil particles have higher surface-area-to-volume ratios and are higher in organic matter content. Therefore, concentrations of organic COPCs, which are a function of the organic carbon content of sorbing media, are expected to be higher in eroded material than in *in situ* soil.

This document is also the source of the following:

- COPC-specific (inorganics only) Kd_s values used to develop a proposed range (0 to 280,000 [mL water/g soil]) of Kd_s values
- A range of soil volumetric water content (θ_{sw}) values of 0.1 (mL water/cm^3 soil) (very gravelly soils) to 0.3 (mL water/cm^3 soil) (heavy loam/clay soils); however, no source or reference is provided for this range.

U.S. EPA. 1994. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes.* Attachment C, *Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document recommends (1) a default soil bulk density value of 1.5 (g soil/cm^3 soil), based on a mean value for loam soil from Carsel, Parrish, Jones, Hansen, and Lamb (1988), and (2) a default soil volumetric water content, θ_{sw}, value of 0.2 (mL water/cm^3 soil), based on U.S. EPA (1993).

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

TABLE B-4-12

DIFFUSION LOAD TO WATER BODY (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Description

This equation calculates the load to the water body due to dry vapor phase diffusion. Uncertainties associated with this equation include the following:

(1) Most of the uncertainties associated with the variables in this equation, specifically those associated with K_v, Q, $Cywv$, and A_w, are site-specific.

(2) This equation assumes a default S_T value for background plus local sources, rather than an S_T value for urban sources. If a specific site is located in an urban area, the use of the latter S_T value may be more appropriate. Specifically, the S_T value for urban sources is about one order of magnitude greater than that for background plus local sources and would result in a lower calculated F_v value; however, the F_v value is likely to be only a few percent lower.

Equation

$$L_{dif} = \frac{K_v \cdot Q \cdot F_v \cdot Cywv \cdot A_w \cdot 1\times10^{-06}}{\frac{H}{R \cdot T_{wk}}}$$

For mercury modeling

$$L_{dif} = \frac{K_v \cdot 0.48Q \cdot F_v \cdot Cywv \cdot A_w \cdot 1\times10^{-06}}{\frac{H}{R \cdot T_{wk}}}$$

Diffusion load to water body is calculated using 0.48Q and $F_v = 0.85$ for divalent mercury. Use $F_v = 0.85$ and H_{Hg2+} for the mercury modeling to calculate L_{RI}. The calculated L_{RI} value is split into the divalent and methyl mercury (MHg) forms based on the 85% Hg^{2+} and 15% MHg speciation split.

$L_{dif}(Hg^{2+}) = 0.85\ L_{dif}$

$L_{dif}(MHg) = 0.15\ L_{dif}$

Variable	Description	Units	Value
L_{dif}	Dry vapor phase diffusion load to water body	g/yr	
K_v	Overall transfer rate coefficient	m/yr	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-4-19. Uncertainties associated with this variable are site-specific.

TABLE B-4-12

DIFFUSION LOAD TO WATER BODY
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
Q	COPC-specific emission rate	g/s	**Varies** This variable is COPC- and site-specific. See Chapters 2 and 3 for guidance on the calculation of this variable. Uncertainties associated with this variable are site-specific.
F_v	Fraction of COPC air concentration in vapor phase	unitless	**0 to 1** This variable is COPC-specific and should be determined from the COPC tables in Appendix A-3. Values are also presented in U.S. EPA (1994), RTI (1992), and NC DEHNR (1997). Values are based on the work of Bidleman (1998), as cited in U.S. EPA (1994) and NC DEHNR (1997). U.S. EPA (1994) presents values for organic COPCs that range from 0.27 to 1. All values presented by U.S. EPA (1994) for inorganic COPCs are given as 0. Uncertainties associated with this variable include the following: (1) This equation assumes a default S_T value for background plus local sources, rather than an S_T value for urban sources. If a specific site is located in an urban area, the use of the latter S_T value may be more appropriate. Specifically, the S_T value for urban sources is about one order of magnitude greater than that for background plus local sources and would result in a lower calculated F_v value; however, the F_v value is likely to be only a few percent lower. (2) According to Bidleman (1988), the equation used to calculate F_v assumes that the variable *c* is constant for all chemicals; however, the value of *c* depends on the chemical (sorbate) molecular weight, the surface concentration for monolayer coverage, and the difference between the heat of desorption from the particle surface and the heat of vaporization of the liquid phase sorbate. To the extent that site- or COPC-specific conditions may cause the value of *c* to vary, uncertainty is introduced if a constant value of *c* issued to calculate F_v.
Cywv	Unitized yearly watershed air concentration from vapor phase	µg-s/g-m^3	**Varies** This variable is COPC- and site-specific, and is determined by air dispersion modeling (see Chapter 3). Uncertainties associated with this variable are site-specific.
A_w	Water body surface area	m^2	**Varies** This variable is site-specific (see Chapter 4). Uncertainties associated with this variable are site-specific. However, it is expected that the uncertainty associated with this variable will be limited, because maps, aerial photographs, and other resources from which water body surface areas can be measured, are readily available.
10^{-6}	Units conversion factor	g/µg	

TABLE B-4-12

DIFFUSION LOAD TO WATER BODY
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

(Page 3 of 4)

Variable	Description	Units	Value
H	Henry's Law constant	atm-m^3/mol	**Varies** This variable is COPC-specific. Discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Values for this variable, estimated by using the parameters and algorithms in Appendix A-3, may under- or overestimate the actual COPC-specific values. As a result, L_{Dif} may be under- or overestimated to a limited degree.
R	Universal gas constant	atm-m^3/mol-K	**8.205 x 10^{-5}**
T_{wk}	Water body temperature	K	**298** This variable is site-specific. U.S. EPA OSW recommends the use of this default value in the absence of site-specific information, consistent with U.S. EPA (1993) and U.S. EPA (1994). The following uncertainty is associated with this variable: To the extent that the default water body temperature value does not accurately represent site-specific or local conditions, L_{dif} will be under- or overestimated.

REFERENCES AND DISCUSSION

Bidleman, T.F. 1988. *"Atmospheric Processes." Environmental Science and Technology.* Volume 22. Number 4. Pages 361-367.

For discussion, see References and Discussion in Table B-1-1.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is a reference source for the equation in Table B-4-12. This document also recommends using the equations in Bidleman (1988) to calculate F_v values for all organics other than dioxins (PCDD/PCDFs). However, the document does not present a recommendation for dioxins. This document also states that metals are generally entirely in the particulate phase ($F_v = 0$), except for mercury, which is assumed to be entirely in the vapor phase. The document does not state whether F_v for mercury should be calculated by using the equations in Bidleman (1988); U.S. EPA assumes that this is the case.

U.S. EPA. 1993. *Addendum to Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Solid Waste and Office Research and Development. Washington, D.C. November 10.

This document recommends a range (10°C to 30°C, 283 K to 303 K) for water body temperature, T_{wk}. No source was identified for this range.

U.S. EPA 1994. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document is cited as the reference source for T_{wk} water body temperature (298 K); however, no references or sources are identified for this value. This document is a reference source for the equation in Table B-4-8. This document also presents values for organic COPCs that range from 0.27 to 1. F_v values for organics other than PCDD/PCDFs are calculated by using the equations presented in Bidleman (1988). The F_v value for PCDD/PCDFs is assumed to be 0.27, based on Lorber (no date). Finally, this document presents F_v values for inorganic COPCs equal to 0, based on the assumption that these COPCs are nonvolatile and 100 percent in the particulate phase and 0 percent in the vapor phase.

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

TABLE B-4-13

UNIVERSAL SOIL LOSS EQUATION (USLE)
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Description

This equation calculates the soil loss rate from the watershed by using the Universal Soil Loss Equation (USLE); the result is used in the soil erosion load equation in Table B-4-11. Estimates of unit soil loss, X_e, should be determined specific to each watershed evaluated. Information on determining site- and watershed-specific values for variables used in calculating X_e is provided in U.S. Department of Agriculture (U.S. Department of Agriculture 1997) and U.S. EPA guidance (U.S. EPA 1985). Uncertainties associated with this equation include the following:

(1) All of the equation variables are site-specific. Use of site-specific values will result in estimates of unit soil loss, X_e, that are under- or overestimated to some unknown degree.

Equation

$$X_e = RF \cdot K \cdot LS \cdot C \cdot PF \cdot \frac{907.18}{4047}$$

Variable	Description	Units	Value
X_e	Unit soil loss	kg/m^2-yr	
RF	USLE rainfall (or erosivity) factor	yr^{-1}	**50 to 300** This value is site-specific and is derived on a storm-by-storm basis. As cited in U.S. EPA (1993b), average annual values have been compiled regionally by Wischmeier and Smith (1978); the recommended range reflects these compiled values. The following uncertainty is associated with this variable: The range of average annual rainfall factors (50 to 300) from Wischmeier and Smith (1978) may not accurately reflect site-specific conditions. Therefore, unit soil loss, X_e, may be under- or overestimated.

TABLE B-4-13

UNIVERSAL SOIL LOSS EQUATION (USLE)
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

(Page 2 of 5)

Variable	Description	Units	Value
K	USLE erodibility factor	ton/acre	**Varies** This value is site-specific. U.S. EPA OSW recommends the use of current guidance (U.S. Department of Agriculture 1997; U.S. EPA 1985) in determining watershed-specific values for this variable based on ite-specific information. A default value of 0.39, as cited in NC DEHNR (1997) and U.S. EPA (1994), was based on a soil organic matter content of 1 percent (Droppo, Strenge, Buck, Hoopes, Brockhaus, Walter, and Whelan 1989), and chosen to be representative of a whole watershed, not just an agricultural field. The following uncertainty is associated with this variable: The use of a site-specific USLE soil erodibility factor, *K*, may cause unit soil loss, X_e, to be under- or overestimated to some unknown degree.
LS	USLE length-slope factor	unitless	**Varies** This value is site-specific. U.S. EPA OSW recommends the use of current guidance (U.S. Department of Agriculture 1997; U.S. EPA 1985) in determining watershed-specific values for this variable based on ite-specific information. A value of 1.5 as cited in NC DEHNR (1997) and U.S. EPA (1994), reflects a variety of possible distance and slope conditions (U.S. EPA 1988), and was chosen to be representative of a whole watershed, not just an agricultural field. The following uncertainty is associated with this variable: A site-specific USLE length-slope factor, *LS*, may not accurately represent site-specific conditions. Therefore, unit soil loss, X_e, may be under- or overestimated to some unknown degree.
C	USLE cover management factor	unitless	**Varies** This value is site-specific. U.S. EPA OSW recommends the use of current guidance (U.S. Department of Agriculture 1997; U.S. EPA 1985) in determining watershed-specific values for this variable based on ite-specific information. The range of values up to 0.1 reflect dense vegetative cover, such as pasture grass; values from 0.1 to 0.7 reflect agricultural row crops; and a value of 1.0 reflects bare soil (U.S. EPA 1993b). U.S. EPA (1993a) recommended a value of 0.1 for both grass and agricultural crops. This range of values was also cited in NC DEHNR (1997). However, U.S. EPA (1994) and NC DEHNR (1997) both recommend a default value of 0.1 to be representative of a whole watershed, not just an agricultural field. The following uncertainty is associated with this variable: The USLE cover management factor, *C*, value determined may not accurately represent site-specific conditions. Therefore, the value for *C* may result in the under- or overestimation of unit soil loss, X_e.

TABLE B-4-13

UNIVERSAL SOIL LOSS EQUATION (USLE)
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
PF	USLE supporting practice factor	unitless	**Varies** This value is site-specific. U.S. EPA OSW recommends the use of current guidance (U.S. Department of Agriculture 1997; U.S. EPA 1985) in determining watershed-specific values for this variable based on ite-specific information. A default value of 1.0, which conservatively represents the absence of any erosion or runoff control measures, was cited in NC DEHNR (1997) and U.S. EPA (1993; 1994). The following uncertainty is associated with this variable: Use of a site-specific USLE supporting practice factor, *PF*, may result in the under- or overestimation of unit soil loss, X_e, depending on the actual extent that there are erosion or runoff control measures in the vicinity of the watershed evaluated.
907.18	Units conversion factor	kg/ton	
4047	Units conversion factor	m^2/acre	

REFERENCES AND DISCUSSION

Droppo, J.G. Jr., D.L. Strenge, J.W. Buck, B.L. Hoopes, R.D. Brockhaus, M.B. Walter, and G. Whelan. 1989. *Multimedia Environmental Pollutant Assessment System (MEPAS) Application Guidance: Volume 2-Guidelines for Evaluating MEPAS Input Parameters.* Pacific Northwest Laboratory. Richland, Washington. December.

This document is cited by U.S. EPA 1994 and NC DEHNR 1997 as the reference source for a USLE erodibility factor value of 0.36, based on a soil organic matter content of 1 percent.

NC DEHNR. 1997. *Final NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document recommended the following:

- A USLE erodibility factor, *K*, value of 0.36 ton/acre
- A USLE length-slope factor, *LS*, value of 1.5 (unitless)
- A range of USLE cover management factor, *C*, values of 0.1 to 1.0; it also recommended a value of 0.1 to be representative of a whole watershed, not just an agricultural field.
- A USLE supporting practice factor, *PF*, value of 1.0

U.S. Department of Agriculture. 1997. *Predicting Soil Erosion by Water: A Guide to Conservation Planning With the Revised Universal Soil Loss Equation (RUSLE).* Agricultural Research Service, Agriculture Handbook Number 703. January.

U.S. EPA. 1985. *Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants in Surface and Ground Water—Part I (Revised).* ORD. Athens, Georgia. EPA/600/6-85/002a.

U.S. EPA. 1988. *Superfund Exposure Assessment Manual.* Office of Solid Waste. Washington, D.C. April.

This document is cited by U.S. EPA 1994 and NC DEHNR 1997 as the reference source for the USLE length-slope factor, *LS*, value of 1.5. This value reflects a variety of possible distance and slope conditions and was chosen to be representative of a whole watershed, not just an agricultural field.

U.S. EPA. 1993a. *Addendum: Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions. Working Group Recommendations.* Office of Solid Waste and Office of Research and Development. Washington, D.C. September 24.

This document cites Wischmeier and Smith (1978) as the source of average annual USLE rainfall factors, *RF*, and states that annual values range from less than 50 for the arid western United States to greater than 300 for the southeast.

This document also recommends the following:

- A USLE cover management factor, *C*, of 0.1 for both grass and agricultural crops
- A USLE supporting practice factor, *PF*, of 1.0, based on the assumed absence of any erosion or runoff control measures

U.S. EPA. 1993b. *Review Draft Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustion Emissions.* Office of Health and Environmental Assessment. Office of Research and Development. EPA-600-AP-93-003. November 10.

This document discusses the USLE cover management factor. This factor, *C*, primarily reflects how erosion is influenced by vegetative cover and cropping practices, such as planting across slope rather than up and down slope. This document discusses a range of *C* values for 0.1 to 1.0; values greater than 0.1 but less than 0.2 are appropriate for agricultural row crops, and a value of 1.0 is appropriate for sites mostly devoid of vegetation.

U.S. EPA. 1994. *Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document recommends the following:

- A USLE erodibility factor, *K*, value of 0.36 ton/acre
- A USLE length-slope factor, *LS*, value of 1.5 (unitless)
- A range of USLE cover management factor, *C*, values of 0.1 to 1.0; it recommends a default value of 0.1 to be representative of a whole watershed, not just an agricultural field.
- A USLE supporting practice factor, *PF*, value of 1.0

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

Wischmeire, W.H., and D.D. Smith. 1978. *Predicting Rainfall Erosion Losses—A Guide to Conservation Planning.* Agricultural Handbook No. 537. U.S. Department of Agriculture Washington, D.C.

This document is cited by U.S. EPA (1993) as the source of average annual USLE rainfall factors, *RF*, compiled regionally. According to U.S. EPA (1993), annual values range from less than 50 for the arid western United States to greater than 300 for the southeast.

TABLE B-4-14

SEDIMENT DELIVERY RATIO (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Description
This equation calculates the sediment delivery ratio for the watershed; the result is used in the soil erosion load equation in Table B-4-11. Uncertainties associated with this equation include the following: (1) The recommended default empirical intercept coefficient, *a*, values are average values based on various studies of sediment yields from various watersheds. Therefore, these default values may not accurately represent site-specific watershed conditions. As a result, use of these default values may under- or overestimate the watershed sediment delivery ratio, *SD*. (2) The recommended default empirical slope coefficient, *b*, value is based on a review of sediment yields from various watersheds. This single default value may not accurately represent site-specific watershed conditions. As a result, use of this default value may under- or overestimate the watershed sediment delivery ratio, *SD*.

Equation

$$SD = a \cdot (A_L)^{-b}$$

Variable	Description	Units	Value
SD	Watershed sediment delivery ratio	unitless	

TABLE B-4-14

SEDIMENT DELIVERY RATIO
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
a	Empirical intercept coefficient	unitless	**0.6 to 2.1** This variable is site-specific and is determined on the basis of the watershed area (Vanoni 1975), as cited in U.S. EPA (1993): Watershed Area (sq. miles) — "*a*" Coefficient (unitless) 0.1 — 2.1 1 — 1.9 10 — 1.4 100 — 1.2 1,000 — 0.6 Note: 1 sq. mile = 2.59×10^6 m^2 The use of these values is consistent with U.S. EPA (1994a), U.S. EPA (1994b), and NC DEHNR (1997). The following uncertainty is associated with this variable: The recommended default empirical intercept coefficient, *a*, values are average values based on various studies of sediment yields from various watersheds. Therefore, these default values may not accurately represent site-specific watershed conditions. As a result, use of these default values may under- or overestimate the watershed sediment delivery ratio, *SD*.
A_L	Total watershed area receiving deposition	m^2	**Varies** This variable is site-specific (see Chapter 4). Uncertainties associated with this variable are site-specific.
b	Empirical slope coefficient	unitless	**0.125** As cited in U.S. EPA (1993), this variable is an empirical constant based on the research of Vanoni (1975), which concludes that sediment delivery ratios vary approximately with negative one-eighth ($^-1/8$) power of the drainage area. The use of this value is consistent with U.S. EPA (1994a), U.S. EPA (1994b), and NC DEHNR (1997). The following uncertainty is associated with this variable: The recommended default empirical slope coefficient, *b*, value is based on a review of sediment yields from various watersheds. This single default value may not accurately represent site-specific watershed conditions. As a result, use of this default value may under- or overestimate the watershed sediment delivery ratio, *SD*.

TABLE B-4-14

SEDIMENT DELIVERY RATIO
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

REFERENCES AND DISCUSSION

NC DEHNR. 1997. *Final NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is cited as one of the reference source documents for the empirical intercept coefficient, *a*, and empirical slope coefficient, *b*, values. This document cites U.S. EPA (1993) as the source of its information.

U.S. EPA. 1993. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, D.C. November.

This document is cited as one of the reference source documents for the empirical intercept coefficient, *a*, and empirical slope coefficient, *b*, values. This document cites Vanoni (1975) as its source of information.

U.S. EPA. 1994a. *Draft Guidance for Performing Screening Level Risk Analysis at Combustor Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* April 15.

This document is cited as one of the reference source documents for the empirical intercept coefficient, *a*, and empirical slope coefficient, *b*, values. This document does not identify Vanoni (1975) as the source of its information.

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document is cited as one of the reference source documents for the empirical intercept coefficient, *a*, and the empirical slope coefficient, *b*, values. This document cites U.S. EPA (1993) as the source of its information.

Vanoni, V.A. 1975. *Sedimentation Engineering.* American Society of Civil Engineers. New York, New York. Pages 460-463.

This document is cited by U.S. EPA (1993) as the source of the equation inTable B-4-14 and the empirical intercept coefficient, *a*, and empirical slope coefficient, *b*, values. Based on various studies of sediment yields from watersheds, this document concludes that the sediment delivery ratios vary approximately with negative one-eighth ($^{-}1/8$) power of the drainage ratio. U.S. EPA has not completed a review of this document.

TABLE B-4-15

TOTAL WATER BODY CONCENTRATION (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Description

This equation calculates the total water body concentration, including the water column and the bed sediment.

Uncertainties associated with this equation include the following:

(1) The default variable values recommended for use in the equation in Table B-4-15 may not accurately represent site-specific water body conditions. The degree of uncertainty associated with the variables Vf_x, A_w, d_{wc}, and d_{bs} is expected to be limited either because the probable ranges for these variables are narrow or information allowing accurate estimates is generally available.

(2) Uncertainty associated with f_{wc} is largely the result of uncertainty associated with default organic carbon (OC) content values and may be significant in specific instances. Uncertainties associated with the total core load into water body (L_T) and overall total water body core dissipation rate constant (k_{wt}) may also be significant in some instances because of the summation of many variable-specific uncertainties.

Equation

$$C_{wtot} = \frac{L_T}{Vf_x \cdot f_{wc} + k_{wt} \cdot A_w \cdot \left(d_{wc} + d_{bs}\right)}$$

For mercury modeling, the total water body concentration is calculated for divalent mercury (Hg^{2+}) and methyl mercury (MHg) using their respective L_T values, f_{wc} values, and k_{wt} values.

Variable	Description	Units	Value
C_{wtot}	Total water body COPC concentration, including water column and bed sediment	g COPC/m^3 water body (equivalent to mg COPC/L water body)	
L_T	Total COPC load to the water body, including deposition, runoff, and erosion	g/yr	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-4-7. Uncertainties associated with L_{DEP}, L_{Dif}, L_{RI}, L_R, and L_E, as presented in the equation in Table B-4-7, are also associated with L_T.

TABLE B-4-15

TOTAL WATER BODY CONCENTRATION (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
Vf_x	Average volumetric flow rate through water body	m^3/yr	**Varies** This variable is site-specific. The following uncertainty is associated with this variable: Use of default average volumetric flow rate (Vf_x) information may not accurately represent site-specific conditions, especially for those water bodies for which flow rate information is not readily available. Therefore, use of default Vf_x values may contribute to the under- or overestimation of total water body COPC concentration, C_{wtot}.
f_{wc}	Fraction of total water body COPC concentration in the water column	unitless	**0 to 1** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-4-16. The following uncertainty is associated with this variable: The default values for the variables in the equation in Table B-4-16 may not accurately represent site- and water body - specific conditions. However, the range of several variables—including d_{bs}, C_{BS}, and θ_{bs}—is relatively narrow. Other variables, such as d_{wc} and d_z, can be reasonably estimated on the basis of generally available information. The largest degree of uncertainty may be introduced by the default medium-specific organic carbon (*OC*) content values. Because *OC* content values may vary widely in different locations in the same medium, by using default values may result in insignificant uncertainty in specific cases.
k_{wt}	Overall total water body dissipation rate constant	yr^{-1}	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-4-17. The following uncertainty is associated with this variable: All of the variables in the equation in Table B-4-17 are site-specific; therefore, the use of default values for any or all of these variables will contribute to the under- or overestimation of C_{wtot}. The degree of uncertainty associated with the variable K_b is expected to be under one order of magnitude and is associated largely with the estimation of the unit soil loss, X_e, values for the variables f_{wc}, K_v, and f_{bs} are dependent on medium-specific estimates of *OC* content. Because *OC* content can vary widely for different locations in the same medium, uncertainty associated with these three may be significant in specific instances.
A_w	Water body surface area	m^2	**Varies** This variable is site-specific. The value selected is assumed to represent an average value for the entire year. See Chapter 4 for procedures to determine this variable. Uncertainties associated with this variable are site-specific. However, it is expected that the uncertainty associated with this variable will be limited because maps, aerial photographs, and other resources from which water body surface areas can be measured, are readily available.

TABLE B-4-15

TOTAL WATER BODY CONCENTRATION
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
d_{wc}	Depth of water column	m	**Varies** This variable is site-specific. The value selected is assumed to represent an average value for the entire year. The following uncertainty is associated with this variable: Use of depth of water column, d_{wc}, values may not accurately reflect site-specific conditions, especially for those water bodies for which depth of water column information is unavailable or outdated. Therefore, use of d_{wc} values may contribute to the under-or overestimation of total water body COPC concentration, C_{wtot}.
d_{bs}	Depth of upper benthic sediment layer	m	**0.03** This variable is site-specific. The value selected is assumed to represent an average value for the entire year. U.S. EPA OSW recommends a default upper benthic sediment depth of 0.03 meter, which is consistent with U.S. EPA (1994) and NC DEHNR (1997) guidance. This value was cited by U.S. EPA (1993); however, no reference was presented. The following uncertainty is associated with this variable: Use of default depth of upper benthic sediment layer, d_{bs}, values may not accurately represent site-specific water body conditions. However, based on the narrow recommended range, any uncertainty introduced is believed to be limited.

TABLE B-4-15

TOTAL WATER BODY CONCENTRATION
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

REFERENCES AND DISCUSSION

NC DEHNR. 1997. *Final NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is also cited as one of the reference source documents for the default depth of upper benthic layer value. The default value is the midpoint of an acceptable range. This document cites U.S. EPA (1993) as its source of information for the range of values for the depth of the upper benthic layer.

U.S. EPA. 1993. *Addendum: Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Working Group Recommendations. Office of Solid Waste and Office of Research and Development. Washington, D.C. September 24.

This document is cited by NC DEHNR (1997) and U.S. EPA (1994) as the source of the range and default value for the depth of the upper benthic layer (d_{bs}).

U.S. EPA. 1994. *Draft Guidance for Performing Screening Level Risk Analysis at Combustor Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* April 15.

This document is cited as one of the reference source documents for the default depth of the upper benthic layer value. The default value is the midpoint of an acceptable range. This document cites U.S. EPA (1993) as its source of information for the range of values for the depth of the upper benthic layer.

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

TABLE B-4-16

FRACTION IN WATER COLUMN AND BENTHIC SEDIMENT (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Description

This equation calculates the fraction of total water body concentration occurring in the water column and the bed sediments.

Uncertainties associated with this equation include the following:

(1) The default variable values may not accurately represent site-specific water body conditions. However, the range of several variables—including d_{bs}, C_{BS}, and θ_{bs}—is relatively narrow. Other variables, such as d_{wc} and d_z, can be reasonably estimated on the basis of generally available information. The largest degree of uncertainty may be introduced by the default medium-specific OC content values. *OC* content values can vary widely for different locations in the same medium. Therefore, the use of default values may introduce significant uncertainty in some cases.

Equations

$$f_{wc} = \frac{(1 + Kd_{sw} \cdot TSS \cdot 1\times10^{-6}) \cdot d_{wc}/d_z}{(1 + Kd_{sw} \cdot TSS \cdot 1\times10^{-6}) \cdot d_{wc}/d_z + (\theta_{bs} + Kd_{bs} \cdot C_{BS}) \cdot d_{bs}/d_z}$$

$$f_{bs} = 1 - f_{wc}$$

For mercury modeling, the fraction in water column (f_{wc}) is calculated for divalent mercury (Hg^{2+}) and methyl mercury (MHg) using their respective Kd_{sw} values and Kd_{bs} values; the fraction in benthic sediment (f_{bs}) is calculated for divalent mercury (Hg^{2+}) and methyl mercury (MHg) using their respective f_{wc} values.

Variable	Description	Units	Value
f_{wc}	Fraction of total water body COPC concentration in the water column	unitless	
f_{bs}	Fraction of total water body COPC concentration in benthic sediment	unitless	

FRACTION IN WATER COLUMN AND BENTHIC SEDIMENT (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
Kd_{sw}	Suspended sediments/surface water partition coefficient	L water/kg suspended sediment (or cm^3 water/kg suspended sediment)	**Varies** This variable is COPC-specific. Discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Kd_{sw} values in Appendix A-3 are based on default *OC* contents for surface water and soil. Kd_{sw} values based on default values may not accurately reflect site- and water body-specific conditions and may under- or overestimate actual Kd_{sw} values. Uncertainty associated with this variable will be reduced if site-specific and medium-specific *OC* estimates are used to calculate Kd_{sw}.
TSS	Total suspended solids concentration	mg/L	**2 to 300** This variable is site-specific. U.S. EPA recommends the use of site- and waterbody specific measured values, representative of long-term average annual values for the water body of concern (see Chapter 5). A value of 10 mg/L was cited by NC DEHNR (1997), U.S. EPA (1993a), and U.S. EPA (1993b) in the absense of site-specific measured data. The following uncertainty is associated with this variable: Limitation on measured data used for determining a water body specific total suspended solids (*TSS*) value may not accurately reflect site- and water body-specific conditions long term. Therefore, the *TSS* value may contribute to the under-or overestimation of f_{wc}.
1×10^{-6}	Units conversion factor	kg/mg	
d_{wc}	Depth of water column	m	**Varies** This variable is site-specific. The value selected is assumed to represent an average value for the entire year. The following uncertainty is associated with this variable: Use of depth of water column, d_{wc}, values may not accurately reflect site-specific conditions, especially for those water bodies for which depth of water column information is unavailable or outdated. Therefore, use of d_{wc} values may contribute to the under- or overestimation of total water body COPC concentration, C_{wtot}.

TABLE B-4-16

FRACTION IN WATER COLUMN AND BENTHIC SEDIMENT
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

(Page 3 of 5)

Variable	Description	Units	Value
d_{bs}	Depth of upper benthic sediment layer	m	**0.03** This variable is site-specific. U.S. EPA OSW recommends a default upper benthic sediment depth of 0.03 meter, which is consistent with U.S. EPA (1994) and NC DEHNR (1997) guidance. This value was cited by U.S. EPA (1993b); however, no reference was presented. The following uncertainty is associated with this variable: Use of default depth of upper benthic sediment layer, d_{bs}, values may not accurately represent site-specific water body conditions. However, any uncertainly introduced is expected to be limited on the basis of the narrow recommended range.
d_z	Total water body depth	m	**Varies** This variable is site-specific. U.S. EPA OSW recommends that the following equation be used to calculate total water body depth, consistent with NC DEHNR (1997): $d_z = d_{wc} + d_{bs}$ The following uncertainty is associated with this variable: Calculation of this variable combines the concentrations associated with the two variables summed, d_{wc} and d_{bs}. Because most of the total water body depth (d_z) is made up of the depth of the water column (d_{wc}), and the uncertainties associated with d_{wc} are not expected to be significant, the total uncertainties associated with this variable, d_z, are also not expected to be significant.
C_{BS}	Bed sediment concentration (or bed sediment bulk density)	g/cm^3 (equivalent to kg/L)	**1.0** This variable is site-specific. U.S. EPA OSW recommends a default value of 1.0, consistent with U.S. EPA (1993a), which states that this value should be reasonable for most applications. The recommended default value is also consistent with other U.S. EPA (1993b), U.S. EPA (1994), and NC DEHNR (1997) guidance. The following uncertainty is associated with this variable: The recommended default value may not accurately represent site- and water body-specific conditions. Therefore, the variable f_{wc} may be under- or overestimated; the assumption that under- or overestimation will be limited is based on the narrow recommended range.

TABLE B-4-16

FRACTION IN WATER COLUMN AND BENTHIC SEDIMENT (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
θ_{bs}	Bed sediment porosity	$L_{water}/L_{sediment}$	**0.6** This variable is site-specific. U.S. EPA OSW recommends a default bed sediment porosity of 0.6 (by using a C_{BS} value of 1 g/cm^3 and a solid density (ρ_s) value of 2.65 kg/L) calculated by using the following equation (U.S. EPA 1993a): $$\theta_{bs} = 1 - C_{BS}/\rho_s$$ This is consistent with other U.S. EPA (1993b), U.S. EPA (1994), and NC DEHNR (1997) guidance. The following uncertainty is associated with this variable: Calculation of this variable combines the uncertainties associated with the two variables, C_{BS} and ρ_s, used in the calculation. To the extent that the recommended default values of C_{BS} and ρ_s do not accurately represent site- and water body-specific conditions, θ_{bs} will be under- or overestimated.
Kd_{bs}	Bed sediment/sediment pore water partition coefficient	L water/kg bottom sediment (or cm^{3}water/g bottom sediment)	**Varies** This variable is COPC-specific. Discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: The Kd_{bs} values in Appendix A-3 are based on default *OC* contents for sediment and soil. Kd_{bs} values based on default *OC* values may not accurately represent site- and water body-specific conditions and may under- or overestimate actual Kd_{bs} values. Uncertainty associated with this variable will be reduced if site- and water body-specific *OC* estimates are used to calculate Kd_{bs}.

TABLE B-4-16

FRACTION IN WATER COLUMN AND BENTHIC SEDIMENT (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

REFERENCES AND DISCUSSION

NC DEHNR. 1997. *Final NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is cited as one of the sources of the range of Kd_s values and assumed *OC* values of 0.075 and 0.04 for surface water and sediment, respectively. This document is also cited as one of the sources of *TSS*. This document cites U.S. EPA (1993b) as its source of information. This document is also cited as the source of the equation for calculating total water body depth. No source of this equation was identified. This document is also cited as one of the reference source documents for the default value for bed sediment porosity. This document cites U.S. EPA (1993b) as its source of information. This document is also cited as one of the reference source documents for the default value for depth of the upper benthic layer. The default value is the midpoint of an acceptable range. This document cites U.S. EPA (1993b) as its source of information for the range of values for the depth of the upper benthic layer. This document is also cited as one of the reference source documents for the default bed sediment concentration. This document cites U.S. EPA (1993b) as its source of information.

U.S. EPA. 1993a. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, D.C. November 1993.

This document is cited as one of the sources of the range of Kd_s values and assumed *OC* values of 0.075 and 0.04 for surface water and sediment, respectively. The generic equation for calculating partition coefficients (soil, surface water, and bed sediments) is $Kd_{ij} = (Koc \cdot OC_i)$. *Koc* is a chemical-specific value; however, *OC* is medium-specific. The range of Kd_s values was based on an assumed *OC* value of 0.01 for soil. Kd_{sw} and Kd_{bs} values were estimated by multiplying the Kd_s values by 7.5 and 4, because the *OC* values for surface water and sediment are 7.5 and 4 times greater than the *OC* value for soil. This document also presents the equation for calculating bed sediment porosity (θ_{bs}); no source of this equation was identified. This document was also cited as the source for the range of the bed sediment concentration (C_{BS}); no original source of this range was identified. Finally, this document recommends that, in the absence of site-specific information, a *TSS* value of 1 to 10 be specified for parks and lakes, and a *TSS* value of 10 to 20 be specified in streams and rivers.

U.S. EPA. 1993b. *Addendum: Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Working Group Recommendations. Office of Solid Waste and Office of Research and Development. Washington, D.C. September 24.

This document is cited by NC DEHNR (1997) as the source of the *TSS* value. This document is also cited by NC DEHNR (1997) and U.S. EPA (1994) as the source of the default bed sediment porosity value and the equation used to calculate the variable, the default bed sediment concentration value, and the range for the depth of the upper benthic layer values.

U.S. EPA. 1994. *Draft Guidance for Performing Screening Level Risk Analysis at Combustor Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* April 15.

This document is cited as one of the reference source documents for the default value for bed sediment porosity. This document cites U.S. EPA (1993b) as its source of information. This document is also cited as one of the reference source documents for the default value for depth of the upper benthic layer. The default value is the midpoint of an acceptable range. This document cites U.S. EPA (1993b) as its source of information for the range of values for the depth of the upper benthic layer. This document is also cited as one of the reference source documents for the default bed sediment concentration. This document cites U.S. EPA (1993b) as its source of information.

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

TABLE B-4-17

OVERALL TOTAL WATER BODY DISSIPATION RATE CONSTANT (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Description

This equation calculates the overall COPC dissipation rate in surface water due to volatilization and benthic burial.

Uncertainties associated with this equation include the following:

(1) All of the variables in the equation in Table B-4-17 are site-specific. Therefore, the use of default values for any or all of these variables will contribute to the under- or overestimation of k_{wt}. The degree of uncertainty associated with the variable k_b is expected to be one order of magnitude at most and is associated with the estimation of the unit soil loss, X_e. Values for the variables f_{wc}, k_v, and f_{bs} are dependent on medium-specific estimates of medium-specific *OC* content. Because *OC* content can vary widely for different locations in the same medium, uncertainty associated with these three variables may be significant in specific instances.

Equation

$$k_{wt} = f_{wc} \cdot k_v + f_{bs} \cdot k_b$$

Variable	Description	Units	Value
k_{wt}	Overall total water body dissipation rate constant	yr^{-1}	
f_{wc}	Fraction of total water body COPC concentration in the water column	unitless	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-4-16. Uncertainties associated with this variable include the following: (1) The default variable values recommended for use in the equation in Table B-4-16 may not accurately represent site-specific water body conditions. However, the range of several variables—including d_{bs}, C_{BS}, and θ_{sw}—is moderate (factors of 5, 3, and 2, respectively); therefore, the degree of uncertainty associated with these variables is expected to be moderate. Other variables, such as d_{wc} and d_z, can be reasonably estimated on the basis of generally available information; therefore, the degree of uncertainty associated with these variables is expected to be relatively small. (2) The largest degree of uncertainty may be introduced by the default medium-specific *OC* content values. *OC* content values are often not readily available and can vary widely for different locations in the same medium. Therefore, the degree of uncertainty may be significant in specific instances.

TABLE B-4-17

OVERALL TOTAL WATER BODY DISSIPATION RATE CONSTANT (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
k_v	Water column volatilization rate constant	yr^{-1}	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-4-18. Uncertainties associated with this variable include the following: (1) All of the variables in the equation in Table B-4-18 are site-specific. Therefore, the use of default values for any or all of these variables could contribute to the under- or overestimation of k_v. (2) The degree of uncertainty associated with the variables d_z and *TSS* is expected to be minimal either because information necessary to estimate these variables is generally available or because the range of probable values is narrow. (3) Values for the variable k_v and Kd_{sw} are dependent on medium-specific estimates of *OC* content. Because *OC* content can vary widely for different locations in the same medium, uncertainty associated with these two variables may be significant in specific instances.
f_{bs}	Fraction of total water body COPC concentration in benthic sediment	unitless	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-4-16. Uncertainties associated with this variable include the following: (1) The default variable values recommended for use in the equation in Table B-4-16 may not accurately represent site-specific water body conditions. However, the range of several variables—including d_{bs}, C_{BS}, and θ_{sw}—is relatively narrow; therefore, the degree of uncertainty associated with these variables is expected to be relatively small. Other variables, such as d_{wc} and d_z, can be reasonably estimated on the basis of generally available information. (2) The largest degree of uncertainty may be introduced by the default medium-specific *OC* contact values. *OC* content values are often not readily available and can vary widely for different locations in the same medium. Therefore, the degree of uncertainty may be significant in specific instances.
k_b	Benthic burial rate constant	yr^{-1}	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-4-22. Uncertainties associated with this variable include the following: (1) All of the variables in the equation in Table B-4-22 are site-specific. Therefore, the use of default values rather than site-specific values, for any or all of these variables, will contribute to the under- or overestimation of K_b. (2) The degree of uncertainty associated with each of these variables is as follows: (1) X_e—about one order of magnitude at most, (2) C_{BS}, d_{bs}, Vf_x, *TSS*, and A_w—limited because of the narrow recommended ranges for these variables or because resources to estimate variable values are generally available, and (3) A_L and *SD*—very site-specific, degree of uncertainty unknown.

TABLE B-4-18

WATER COLUMN VOLATILIZATION LOSS RATE CONSTANT (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Description

This equation calculates the water column COPC loss rate constant due to volatilization. Uncertainty associated with this equation includes the following:

All of the variables in the equation in Table B-4-18 are site-specific. Therefore, the use of default values for any or all of these variables will contribute to the under- or over estimation of k_v. The degree of uncertainty associated with the variables d_{wc}, d_{bs}, and d_z are expected to be minimal either because information necessary to estimate these variables is generally available or because the range of probable values is narrow. Values for the variables K_v and Kd_{sw} are dependent on medium-specific estimates of *OC* content. Because *OC* content can vary widely for different locations in the same medium, uncertainty associated with these two variables may be significant in specific instances.

Equation

$$k_v = \frac{K_v}{d_z \cdot (1 + Kd_{sw} \cdot TSS \cdot 10^{-6})}$$

For mercury modeling, the water column volatilization loss rate constant is calculated for divalent mercury (Hg^{2+}) and methyl mercury (MHg) using their respective fate and transport parameters.

Variable	Description	Units	Value
k_v	Water column volatilization rate constant	yr^{-1}	
K_v	Overall COPC transfer rate coefficient	m/yr	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-4-19. Uncertainties associated with this variable include the following: (1) All of the variables in the equation in Table B-4-19—except *R*, the universal gas constant, which is well-established—are site-specific. Therefore, the use of default values, for any or all these variables, could contribute to the under- or overestimation of K_v. (2) The degree of uncertainty associated with the variables *H* and T_{wk} is expected to be minimal; values for *H* are well-established, and average water body temperature, T_{wk}, will likely vary less than 10 percent of the default value. (3) The uncertainty associated with the variables K_L and K_G is attributable largely to medium-specific estimates of organic carbon, *OC*, content. Because *OC* content values can vary widely for different locations in the same medium, the use of default values may generate significant uncertainty in specific instances. Finally, the origin of the recommended temperature correction factor, θ, value is unknown; therefore, the degree of associated uncertainty is also unknown.

TABLE B-4-18

WATER COLUMN VOLATILIZATION LOSS RATE CONSTANT (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
d_z	Total water body depth	m	**Varies** This variable is site-specific. U.S. EPA OSW recommends that the following equation be used to calculate total water body depth, consistent with NC DEHNR (1997): $d_z = d_{wc} + d_{bs}$ The following uncertainty is associated with this variable: Calculation of this variable combines the concentrations associated with the two variables summed, d_{wc} and d_{bs}. Because most of the total water body depth (d_z) is made up of the depth of the water column (d_{wc}), and the uncertainties associated with d_{wc} are not expected to be significant, the total uncertainties associated with this variable, d_z, are also not expected to be significant.
d_{wc}	Depth of water column	m	**Varies** This variable is site-specific. The following uncertainty is associated with this variable: Use of default values for depth of water column, d_{wc}, may not accurately reflect site-specific conditions, especially for water bodies for which depth of water column information is unavailable or outdated. Therefore, use of default d_{wc} values may contribute to the under- or overestimation of total water body COPC concentration, C_{wtot}. However, the degree of under- or overestimation is not expected to be significant.
d_{bs}	Depth of upper benthic sediment layer	m	**0.03** This variable is site-specific. U.S. EPA OSW recommends a default upper-benthic sediment depth of 0.03 meters, which is based on the center of a range cited by U.S. EPA (1993b). This is consistent with U.S. EPA (1994) and NC DEHNR (1997). The following uncertainty is associated with this variable: Use of default values for depth of upper benthic sediment layer, d_{bs}, may not accurately represent site-specific water body conditions. However, any uncertainty introduced is expected to be limited, based on the narrow recommended range.

TABLE B-4-18

WATER COLUMN VOLATILIZATION LOSS RATE CONSTANT (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
Kd_{sw}	Suspended sediments/surface water partition coefficient	L water/kg suspended sediments	**Varies** This variable is COPC-specific. Discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: The Kd_{sw} values presented in Appendix A-3 are calculated on the basis of default *OC* contents for surface water and soil. Kd_{sw} values based on default values may not accurately reflect site-and water body-specific conditions and may under- or overestimate actual Kd_{sw} values. Uncertainty associated with this variable will be reduced if site-specific and medium-specific *OC* estimates are used to calculate Kd_{sw}.
TSS	Total suspended solids concentration	mg/L	**2 to 300** This variable is site-specific. U.S. EPA recommends the use of site- and waterbody specific measured values, representative of long-term average annual values for the water body of concern (see Chapter 5). A value of 10 mg/L was cited by NC DEHNR (1997), U.S. EPA (1993a), and U.S. EPA (1993b) in the absense of site-specific measured data. The following uncertainty is associated with this variable: Limitation on measured data used for determining a water body specific total suspended solids (*TSS*) value may not accurately reflect site- and water body-specific conditions long term. Therefore, the *TSS* value may contribute to the under-or overestimation of f_{wc}.
1×10^{-6}	Units conversion factor	kg/mg	

REFERENCES AND DISCUSSION

NC DEHNR. 1997. *Final NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is cited as the source of the equation for calculating total water body depth. No source of this equation was identified. This document is also cited as one of the sources of the range of Kd_s values and an assumed *OC* value of 0.075 for surface water. This document is also cited as one of the sources of *TSS*. This document cites U.S. EPA (1993b) as its source of information.

U.S. EPA. 1993a. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, D.C. November 1993.

This document is cited as one of the sources of the range of Kd_s values and assumed *OC* content value of 0.075 for surface water. The generic equation for calculating partition coefficients (soil, surface water, and bed sediments) is as follows: $Kd_{ij} = K_{ocj}\ OC_i$. K_{oc} is a chemical-specific value; however, *OC* is medium-specific. The range of Kd_s values was based on an assumed *OC* value of 0.01 for soil. This document is one of the sources cited that assumes an *OC* value of 0.075 for surface water. Therefore, the Kd_{sw} value was estimated by multiplying the Kd_s values by 7.5, because the *OC* value for surface water is 7.5 times greater than the *OC* value for soil.

U.S. EPA. 1993b. *Addendum: Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Working Group Recommendations. Office of Solid Waste and Office of Research and Development. Washington, D.C. September 24.

This document is cited by U.S. EPA (1994) and NC DEHNR (1997) as the source of the range and default value for the depth of the upper benthic layer (d_{bs}). This document is also cited by NC DEHNR (1997) as the source of the *TSS* value.

U.S. EPA. 1994. *Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facility Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facility.* April 15.

This document is cited as one of the reference source documents for the default value of the depth of the upper benthic layer. The default value is the midpoint of an acceptable range. This document cites U.S. EPA (1993b) as its source of information.

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

OVERALL COPC TRANSFER RATE COEFFICIENT (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Description

This equation calculates the overall transfer rate of contaminants from the liquid and gas phases in surface water.

Uncertainties associated with this equation include the following:

(1) All of the variables in the equation in Table B-4-19—except *R*, the universal gas constant, which is well-established—are site-specific. Therefore, the use of any or all of these variables will contribute to the under- or overestimation of K_v.

(2) The degree of uncertainty associated with the variables *H* and T_{wk} is believed to be minimal. Values for *H* are well-established, and average water body temperature will likely vary less than 10 percent of the default value.

(3) The uncertainty associated with the variables K_v and K_G is attributable largely to medium-specific estimates of *OC* content. Because *OC* content values can vary widely for different locations in the same medium, the use of default values may generate significant uncertainty in specific instances. Finally, the origin of the recommended value is unknown; therefore, the degree of associated uncertainty is also unknown.

Equation

$$K_v = \left[K_L^{-1} + \left(K_G \cdot \frac{H}{R \cdot T_{wk}} \right)^{-1} \right]^{-1} \cdot \theta^{(T_{wk} - 293)}$$

For mercury modeling, the overall COPC transfer rate coefficient is calculated for divalent mercury (Hg^{2+}) and methyl mercury (MHg) using their respective fate and transport parameters.

Variable	Description	Units	Value
K_v	Overall COPC transfer rate coefficient	m/yr	

Variable	Description	Units	Value
K_L	Liquid phase transfer coefficient	m/yr	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-4-20. Uncertainties associated with this variable include the following: All of the variables in the equation in Table B-4-20 are site-specific. Therefore, the use of default values rather than site-specific values, for any or all of these variables, will contribute to the under- or overestimation of K_v. The degree of uncertainty associated with these variables is as follows: a) Minimal or insignificant uncertainty is assumed to be associated with six variables—D_w, u, d_z, ρ_a, ρ_w, and μ_w—either because of narrow recommended ranges for these variables or because information to estimate variable values is generally available. b) No original sources were identified for the equations used to derive recommended values or specific recommended values for variables C_d, k, and λ_z. Therefore, the degree and direction of any uncertainties associated with these variables are unknown. c) Uncertainties associated with the variable W are site-specific.
K_G	Gas phase transfer coefficient	m/yr	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-4-21. Uncertainties associated with this variable include the following: All of the variables in the equation in Table B-4-21, with the exception of k, are site-specific. Therefore, the use of default values rather than site-specific values, for any or all of these variables, will contribute to the under- or overestimation of K_G. The degree of uncertainty associated with each of these variables is as follows: a) Minimal or insignificant uncertainty is assumed to be associated with the variables D_a, μ_a, and ρ_a, because these variables have been extensively studied, and equation procedures are well-established. b) No original sources were identified for equations used to derive recommended values or specific recommended values for variables C_d, k, and d_z. Therefore, the degree and direction of any uncertainties are unknown. c) Uncertainties associated with the variable W are site-specific and cannot be readily estimated.

TABLE B-4-19

OVERALL COPC TRANSFER RATE COEFFICIENT (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
H	Henry's Law constant	atm-m^3/mol	**Varies** This variable is COPC-specific. Discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Values for this variable, estimated by using the parameters and algorithms in Appendix A-3, may under- or overestimate the actual COPC-specific values. As a result, K_v may be under- or overestimated to a limited degree.
R	Universal gas constant	atm-m^3/mol-K	**8.205×10^{-5}** There are no uncertainties associated with this constant.
T_{wk}	Water body temperature	K	**298** This variable is site-specific. U.S. EPA OSW recommends the use of this default value when site-specific information is not available; this is consistent with U.S. EPA (1993a), U.S. EPA (1993b), and U.S. EPA (1994). The following uncertainty is associated with this variable: To the extent that the default water body temperature value does not accurately represent site- and water body-specific conditions, K_v, will be under- or overestimated to a limited degree.
θ	Temperature correction factor	unitless	**1.026** This variable is site-specific. U.S. EPA OSW recommends the use of this default value when site-specific information is not available; this is consistent with U.S. EPA (1993a), U.S. EPA (1993b), and U.S. EPA (1994). The following uncertainty is associated with this variable: The purpose and sources of this variable and the recommended value are unknown.

OVERALL COPC TRANSFER RATE COEFFICIENT (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

REFERENCES AND DISCUSSION

U.S. EPA. 1993a. *Addendum: Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Working Group Recommendations. Office of Solid Waste and Office of Research and Development. Washington, D.C. September 24.

This document is the reference source for the equation in Table B-4-19, including the use of the temperature correction fraction (θ).

This document is also cited by U.S. EPA (1994) and NC DEHNR (1997) as the source of the T_{wk} value of 298 K (298 K = 25°C) and the default temperature correction fraction, θ, value of 1.026.

U.S. EPA. 1993b. *Addendum to Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Solid Waste and Office of Research and Development. Washington, D.C. November 10.

This document recommends the T_{wk} value of 298 K (298 K = 25°C) and the temperature correction fraction value, θ, of 1.026. No source was identified for these values.

U.S. EPA. 1994. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document is cited as the reference source for water body temperature (T_{wk}) and temperature correction factor (θ). This document apparently cites U.S. EPA (1993a) as its source of information.

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

LIQUID PHASE TRANSFER COEFFICIENT (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Description

This equation calculates the rate of COPC transfer from the liquid phase for a flowing or quiescent water body.

Uncertainties associated with this equation include the following:

(1) Minimal or insignificant uncertainly is assumed to be associated with the following six variables: D_w, u, d_z, ρ_a, ρ_w, and μ_w.
(2) No original sources were identified for equations used to derive recommended values or specific recommended values for the following three variables: C_d, k, and d_z. Therefore, the degree and duration of any uncertainties associated with these variables is unknown.
(3) Uncertainties associated with the variable W are site-specific.

Equation

For flowing streams or rivers

$$K_L = \sqrt{\frac{(1 \times 10^{-4}) \cdot D_w \cdot u}{d_z}} \cdot 3.1536 \times 10^7$$

For quiescent lakes or ponds

$$K_L = (C_d^{0.5} \cdot W) \cdot \left(\frac{\rho_a}{\rho_w}\right)^{0.5} \cdot \frac{k^{0.33}}{\lambda_z} \cdot \left(\frac{\mu_w}{\rho_w \cdot D_w}\right)^{-0.67} \cdot 3.1536 \times 10^7$$

For mercury modeling, the liquid phase transfer coefficient is calculated for divalent mercury (Hg^{2+}) and methyl mercury (MHg) using their respective fate and transport parameters.

Variable	Description	Units	Value
K_L	Liquid phase transfer coefficient	m/yr	

TABLE B-4-20

LIQUID PHASE TRANSFER COEFFICIENT (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

(Page 2 of 5)

Variable	Description	Units	Value
D_w	Diffusivity of COPC in water	cm^2/s	**Varies** This variable is COPC-specific. Discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: The default D_w values may not accurately represent the behavior of COPCs under water body-specific conditions. However, the degree of uncertainty is expected to be minimal.
u	Current velocity	m/s	**Varies** This variable is site-specific, and should relate to the volumetric flow rate of the waterbody evaluated. The following uncertainty is associated with this variable: Sources of values for this variable are reasonably available for most large surface water bodies. Estimated values for this variable be necessary for smaller water bodies; uncertainty will be associated with these estimates. The degree of uncertainty associated with this variable is not expected to be significant.
d_z	Total water body depth	m	**Varies** This variable is site-specific, and, in most cases, should represent the average mean across the waterbody evaluated. U.S. EPA OSW recommends that this value be calculated by using the following equation, consistent with U.S. EPA (1994) and NC DEHNR (1997): $d_z = d_{wc} + d_{bs}$ No reference was cited for this recommendation. The following uncertainty is associated with this variable: Calculation of this variable combines the concentrations associated with the two variables summed, d_{wc} and d_{bs}. Because most of the total water body depth (d_z) is made up of the depth of the water column (d_{wc}), and the uncertainties associated with d_{wc} are not expected to be significant, the total uncertainties associated with this variable d_z are also not expected to be significant.
3.1536×10^7	Units conversion factor	s/yr	

Variable	Description	Units	Value
C_d	Drag coefficient	unitless	**0.0011** This variable is site-specific. U.S. EPA OSW recommends a default value of 0.0011, consistent with U.S. EPA (1993a), U.S. EPA (1993b), U.S. EPA (1994), and NC DEHNR (1997). The following uncertainty is associated with this variable: The original source of this variable value is unknown. Therefore, any uncertainties associated with its use are also unknown.
W	Average annual wind speed	m/s	**3.9** Consistent with U.S. EPA (1990), U.S. EPA OSW recommends a default value of 3.9 m/s. See Chapter 3 for guidance regarding the references and methods used to determine a site-specific value that isconsistent with air dispersion modeling. The following uncertainty is associated with this variable: To the extent that site-specific or local values for this variable are not available, default values may not accurately represent site-specific conditions. The uncertainty associated with the selection of a single value from within the range of windspeeds at a single location may be more significant than the uncertainty associated with choosing a single windspeed to represent all locations.
ρ_a	Density of air	g/cm^3	**0.0012** U.S. EPA OSW recommends this default value when site-specific information is not available. This is consistent with U.S. EPA (1994) and NC DEHNR (1997), both of which cite Weast (1979) as the source of this value. This value applies at standard conditions (25°C or 298 K and 1 atm or 750 mm Hg). The density of air will vary with temperature.
ρ_w	Density of water	g/cm^3	**1** U.S. EPA recommends this default value, consistent with U.S. EPA (1994) and NC DEHNR (1997), both of which cite Weast (1979) as the source of this value. This value applies at standard conditions (25°C or 298 K and 1 atm or 750 mm Hg). There is no significant uncertainty associated with this variable.

TABLE B-4-20

LIQUID PHASE TRANSFER COEFFICIENT (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

(Page 4 of 5)

Variable	Description	Units	Value
k	von Karman's constant	unitless	**0.4** This value is a constant. U.S. EPA OSW recommends the use of this value, consistent with U.S. EPA (1994) and NC DEHNR (1997). The following uncertainty is associated with this variable: The original source of this variable value is unknown. Therefore, any uncertainties associated with its use are also unknown.
λ_z	Dimensionless viscous sublayer thickness	unitless	**4** This value is site-specific. U.S. EPA OSW recommends the use of this default value when site-specific information is not available; consistent with U.S. EPA (1994) and NC DEHNR (1997). The following uncertainty is associated with this variable: The source of the value for this variable is unknown. Therefore, any uncertainties associated with its use cannot be quantified.
μ_w	Viscosity of water corresponding to water temperature	g/cm-s	**1.69×10^{-02}** U.S. EPA OSW recommends this default value, consistent with U.S. EPA (1994) and NC DEHNR (1997), which both cite Weast (1979) as the source of this value. This value applies at standard conditions (25°C or 298 K and 1 atm or 760 mm Hg). There is no significant uncertainty associated with this variable.

REFERENCES AND DISCUSSION

NC DEHNR. 1997. *Final NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is cited as one of the sources of the range of D_w values and assumed C_d, ρ_a, ρ_w, k, α_λ, and μ_w values of 0.0011, 1.2×10^{-3}, 1, 0.4, 4, and 1.69×10^{-2}, respectively. This document cites (1) Weast (1979) as its source of information regarding ρ_a, ρ_w, and μ_w; and (2) U.S. EPA (1993a) as its source of information regarding C_d, k, and d_z.

U.S. EPA. 1993a. *Addendum: Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Working Group Recommendations. Office of Solid Waste and Office of Research and Development. Washington, D.C. September 24.

This document is cited by U.S. EPA (1994) and NC DEHNR (1997) as the source of the recommended drag coefficient (C_d) value of 0.0011 and the recommended von Karman's constant (k) value of 0.4. The original sources of variable values are not identified.

U.S. EPA. 1993b. *Addendum to Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Solid Waste and Office of Research and Development. Washington, D.C. November 10.

This document recommends a value of 0.0011 for the drag coefficient (C_d) variable or a value of 0.4 for von Karman's constant (k). No sources are cited for these values.

U.S. EPA. 1994. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document is cited as one of the sources of the range of D_w values and assumed C_d, ρ_a, ρ_w, k, λ_z, and μ_w values of 0.0011, 1.2×10^{-3}, 1, 0.4, 4, and 1.69×10^{-2}, respectively. This document cites (1) Weast (1979) as its source of information regarding ρ_a, ρ_w, and μ_w; and (2) U.S. EPA (1993a) as its source of information regarding C_d, k, and d_z.

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

Weast, R. C. 1979. *CRC Handbook of Chemistry and Physics.* 60th ed. CRC Press, Inc. Cleveland, Ohio.

This document is cited as the source of ρ_a, ρ_w, and μ_w variables of 1.2×10^{-3}, 1, and 1.69×10^{-2}, respectively.

TABLE B-4-21

GAS PHASE TRANSFER COEFFICIENT
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Description

This equation calculates the rate of COPC transfer from the gas phase for a flowing or quiescent water body. Uncertainties associated with this equation include the following:

(1) Minimal or insignificant uncertainty is assumed to be associated with the variables D_a, μ_a, and ρ_a.
(2) No original sources were identified for equations used to derive recommended values or specific recommended values for variables C_d, k, and λ_z. Therefore, the degree and direction of any uncertainties associated with these variables are unknown.
(3) Uncertainties associated with the remaining variables are site-specific.

Equation

Flowing streams or rivers

$$K_G = 36500 \ m/yr$$

Quiescent lakes or ponds

$$K_G = (C_d^{0.5} \cdot W) \cdot \frac{k^{0.33}}{\lambda_z} \cdot \left(\frac{\mu_a}{\rho_a \cdot D_a}\right)^{-0.67} \cdot 3.1536\times10^7$$

For mercury modeling, the gas phase transfer coefficient is calculated for divalent mercury (Hg^{2+}) and methyl mercury (MHg) using their respective fate and transport parameters.

Variable	Description	Units	Value
K_G	Gas phase transfer coefficient	m/yr	
C_d	Drag coefficeint	unitless	**0.0011** This variable is site-specific. U.S. EPA recommends the use of this default value when site-specific information is not available, consistent with U.S. EPA (1993a), U.S. EPA (1993b), U.S. EPA (1994), and NC DEHNR (1997). The following uncertainty is associated with this variable: The original source of this variable is unknown. Therefore, any uncertainties associated with its use are also unknown.

TABLE B-4-21

GAS PHASE TRANSFER COEFFICIENT (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
W	Average annual wind velocity	m/s	**3.9** Consistent with U.S. EPA (1990), U.S. EPA OSW recommends a default value of 3.9 m/s. See Chapter 3 for guidance regarding the references and methods used to determine a site-specific value that isconsistent with air dispersion modeling. The following uncertainty is associated with this variable: To the extent that site-specific or local values for this variable are not available, default values may not accurately represent site-specific conditions. The uncertainty associated with the selection of a single value from within the range of windspeeds at a single location may be more significant than the uncertainty associated with choosing a single windspeed to represent all locations.
k	von Karman's constant	unitless	**0.4** This value is a constant. U.S. EPA OSW recommends the use of this value, consistent with U.S. EPA (1994) and NC DEHNR (1997). The following uncertainty is associated with this variable: The original source of this variable is unknown. Therefore, any uncertainties associated with its use are also unknown.
λ_z	Dimensionless viscous sublayer thickness	unitless	**4** This value is site-specific. U.S. EPA OSW recommends the use of this default value when site-specific information is not available, consistent with U.S. EPA (1994) and NC DEHNR (1997). The following uncertainty is associated with this variable: The original source of this variable is unknown. Therefore, any uncertainties associated with its use are also unknown.
μ_a	Viscosity of air	g/cm-s	**1.81×10^{-04}** U.S. EPA OSW recommends the use of this default value when site-specific information is not available, consistent with U.S. EPA (1994) and NC DEHNR (1997), both of which cite Weast (1979) as the source of their information. There is no significant uncertainty associated with this variable.

TABLE B-4-21

GAS PHASE TRANSFER COEFFICIENT
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

(Page 3 of 4)

Variable	Description	Units	Value
ρ_a	Density of air	g/cm^3	**0.0012** U.S. EPA OSW recommends the use of this default value when site-specific information is not available, consistent with U.S. EPA (1994) and NC DEHNR (1997), both of which cite Weast (1979) as the source of this value. This value applies at standard conditions (25°C or 298 K and 1 atm or 760 mm Hg). The density of air will vary with temperature.
D_a	Diffusivity of COPC in air	cm^2/s	**Varies** This variable is COPC-specific. Discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: The recommended D_a values may not accurately represent the behavior of COPCs under water body-specific conditions. However, the degree of uncertainty is expected to be minimal.
3.1536×10^7	Units conversion factor	s/yr	

REFERENCES AND DISCUSSION

NC DEHNR. 1997. *Final NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is cited as one of the sources of the variables ρ_a, k, λ_z, and μ_a values of 1.2 x 10^{-3}, 0.4, 4, and 1.81 x 10^{-04}, respectively. This document cites (1) Weast (1979) as its source of information for ρ_a and μ_a, and (2) U.S. EPA (1993a) as its source of information for k and λ_z.

U.S. EPA. 1993a. *Addendum: Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustion Emissions.* Working Group Recommendations. Office of Solid Waste, and Office of Research and Development. Washington, D.C. September 24.

This document is cited by U.S. EPA (1994) and NC DEHNR (1997) as the source of (1) the recommended drag coefficient (C_d) value of 0.0011, (2) the recommended von Karman's constant (k) value of 0.4, and (3) the recommended dimensionless viscous sublayer thickness (λ_z) value of 4. The original sources of these variable values are not identified.

U.S. EPA. 1993b. *Addendum to Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Solid Waste, and Office of Research and Development. Washington, D.C. November 10.

This document recommends (1) a value of 0.0011 for the drag coefficient (C_d) variable, (2) a value of 0.4 for von Karman's constant (K), and (3) a value of 4 for the dimensionless viscous sublayer thickness (λ_z) variable. The original sources of the variable values are not identified.

U.S. EPA. 1994. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document is cited as one of the sources of the variables ρ_a, k, λ_z, and μ_a values of 1.2 x 10^{-3}, 0.4, 4, and 1.81 x 10^{-04}, respectively. This document cites (1) Weast (1979) as its source of information for ρ_a and μ_a, and (2) U.S. EPA (1993a) as its source of information for k and λ_z.

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

Weast, R.C. 1979. *CRC Handbook of Chemistry and Physics.* 60th ed. CRC Pres, Inc. Cleveland, Ohio.

This document is cited as the source of ρ_a, ρ_w, and μ_a variables of 1.2 x 10^{-3}, 1, and 1.69 x 10^{-2}, respectively.

BENTHIC BURIAL RATE CONSTANT (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Description

This equation calculates the water column loss constant due to burial in benthic sediment.

Uncertainties associated with this equation include the following:

(1) All of the variables in the equation in Table B-4-22 are site-specific. Therefore, the use of default values rather than site-specific values, for any or all of these variables, will contribute to the under- or overestimation of k_b. The degree of uncertainty associated with each of these variables is as follows: (a) X_e—about one order of magnitude at the most, (b) C_{BS}, d_{bs}, Vf_x, TSS, and A_w—limited because of the narrow recommended ranges for these variables or because resources to estimate variable values are generally available, (c) A_L and SD—very site-specific, degree of uncertainty unknown.

Based on the possible ranges for the input variables to this equation, values of k_b can range over about one order of magnitude.

Equation

$$k_b = \left(\frac{X_e \cdot A_L \cdot SD \cdot 1\times10^3 - Vf_x \cdot TSS}{A_w \cdot TSS} \right) \cdot \left(\frac{TSS \cdot 1\times10^{-6}}{C_{BS} \cdot d_{bs}} \right)$$

Variable	Description	Units	Value
k_b	Benthic burial rate constant	yr^{-1}	
X_e	Unit soil loss	kg/m^2-yr	**Varies** This variable is site-specific and is calculated by using the equation in Table B-4-13. The following uncertainty is associated with this variable: All of the variables in the equation used to calculate unit soil loss, X_e, are site-specific. Use of default values rather than site-specific values, for any or all of the equation variables, will result in estimates of X_e that under- or overestimate the actual value. The degree or magnitude of any under- or overestimation is expected to be about one order of magnitude or less.
A_L	Total watershed area receiving deposition	m^2	**Varies** This variable is site-specific (see Chapter 4). Uncertainties associated with this variable are site-specific.

BENTHIC BURIAL RATE CONSTANT (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
SD	Watershed sediment delivery ratio	unitless	**Varies** This value is site-specific and is calculated by using the equation in Table B-4-14. Uncertainties associated with this variable include the following: (1) The default values for empirical intercept coefficient, *a*, recommended for use in the equation in Table B-4-14, are average values based on various studies of sediment yields from various watersheds. Therefore, these default values may not accurately represent site-specific watershed conditions. As a result, use of these default values may contribute to under- or overestimation of the benthic burial rate constant, k_b. (2) The default value for empirical slope coefficient, *b*, recommended for use in the equation in Table B-4-14 is based on a review of sediment yields from various watersheds. This single default value may not accurately represent site-specific watershed conditions. As a result, use of this default value may contribute to under-or overestimation of k_b.
1×10^3	Units conversion factor	g/kg	
Vf_x	Average volumetric flow rate through water body	m^3/yr	**Varies** This variable is site-specific. U.S. EPA recommends the use of site- and waterbody specific measured values, representative of long-term average annual values for the water body of concern. The following uncertainty is associated with this variable: Use of default average volumetric flow rate, Vf_x, values may not accurately represent site-specific water body conditions. Therefore, the use of such default values may contribute to the under- or overestimation of k_b. However, it is expected that the uncertainty associated with this variable will be limited, because resources such as maps, aerial photographs, and gauging station measurements—from which average volumetric flow rate through water body, Vf_x, can be estimated—are generally available.
TSS	Total suspended solids concentration	mg/L	**2 to 300** This variable is site-specific. U.S. EPA recommends the use of site- and waterbody specific measured values, representative of long-term average annual values for the water body of concern (see Chapter 5). A value of 10 mg/L was cited by NC DEHNR (1997), U.S. EPA (1993a), and U.S. EPA (1993b) in the absense of site-specific measured data. The following uncertainty is associated with this variable: Limitation on measured data used for determining a water body specific total suspended solids (*TSS*) value may not accurately reflect site- and water body-specific conditions long term. Therefore, the *TSS* value may contribute to the under-or overestimation of f_{wc}.

TABLE B-4-22

BENTHIC BURIAL RATE CONSTANT
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

(Page 3 of 4)

Variable	Description	Units	Value
A_w	Water body surface area	m^2	**Varies** This variable is site-specific. The value selected is assumed to represent an average value for the entire year. See Chapter 4 for guidance regarding the references and methods used to determine this value. Uncertainties associated with this variable are site-specific. However, it is expected that the uncertainty associated with this variable will be limited, because maps, aerial photographs—and other resources from which water body surface area, A_w, can be measured—are readily available.
1×10^{-6}	Units conversion factor	kg/mg	
C_{BS}	Bed sediment concentration	g/cm^3	**1.0** This variable is site-specific. U.S. EPA OSW recommends a default value of 1.0, consistent with U.S. EPA (1993b), which states that this value should be reasonable for most applications. No reference is cited for this recommendation. The recommended default value is also consistent with U.S. EPA (1993a), U.S. EPA (1993b), U.S. EPA (1994), and NC DEHNR (1997). The following uncertainty is associated with this variable: The recommended value may not accurately represent site-specific water body conditions.
d_{bs}	Depth of upper benthic sediment layer	m	**0.03** This variable is site-specific. The value selected is allowed to represent an average value for the entire year. U.S. EPA OSW recommends a default upper-benthic sediment depth of 0.03 meters, which is based on the center of the range cited by U.S. EPA (1993a) and U.S. EPA (1993b). This value is also consistent with U.S. EPA (1994) and NC DEHNR (1997). The following uncertainty is associated with this variable: The recommended default value for depth of upper benthic sediment layer, d_{bs}, may not accurately represent site-specific water body conditions. Therefore, use of this default value may contribute to the under- or overestimation of k_b. However, the degree of uncertainty associated with this variable is expected to be limited because of the narrow recommended range.

BENTHIC BURIAL RATE CONSTANT
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

REFERENCES AND DISCUSSION

NC DEHNR. 1997. *FinalNC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is cited as one of the sources of the range of all recommended specific C_{BS} and d_{bs} values. This document cites U.S. EPA (1993a) as its source.

U.S. EPA. 1993a. *Addendum: Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Working Group Recommendations. Office of Solid Waste, and Office of Research and Development. Washington, D.C. September 24.

This document is cited by U.S. EPA (1994) and NC DEHNR (1997) as the source of (1) the *TSS* value, (2) the range and recommended C_{BS} value, and (3) the range and recommended depth of upper benthic layer (d_{bs}) value.

U.S. EPA 1993b. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, D.C. November.

This document states that the upper benthic sediment depth, d_{bs}, representing the portion of the bed in equilibrium with the water column, cannot be precisely specified. However, the document states that values from 0.01 to 0.05 meters would be appropriate. This document also recommends a *TSS* value of 10 mg/L and a specific bed sediment concentration (C_{BS}) value.

U.S. EPA 1994. *Draft Guidance for Performing Screening Level Risk Analysis at Combustor Facilities Burning Hazardous Waste. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* April 15.

This document is cited as one of the reference sources for the d_{bs} value. The recommended value is the midpoint of an acceptable range. This document is also cited as one of the reference source documents for the default C_{BS} value. This document cites U.S. EPA (1993a) as its source.

TABLE B-4-23

TOTAL WATER COLUMN CONCENTRATION (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Description

This equation calculates the total water column concentration of COPCs including (1) both dissolved COPCs and (2) COPCs sorbed to suspended solids. Uncertainties associated with this equation include the following:

(1) All of the variables in the equation in Table B-4-23 are COPC- and site-specific. Therefore, the use of default values rather than site-specific values, for any or all of these variables, will contribute to the under- or overestimation of C_{wctot}.

The degree of uncertainly associated with the variables d_{wc} and d_{bs} is expected to be minimal either because information for estimating a variable (d_{wc}) is generally available or because the probable range for a variable (d_{bs}) is narrow. The uncertainty associated with the variables f_{wc} and C_{wtot} is associated with estimates of *OC* content. Because *OC* content values can vary widely for different locations in the same medium, the uncertainty associated with using default *OC* values may be significant in specific cases.

Equation

$$C_{wctot} = f_{wc} \cdot C_{wtot} \cdot \frac{d_{wc} + d_{bs}}{d_{wc}}$$

For mercury modeling, the total water column concentration is calculated for divalent mercury (Hg^{2+}) and methyl mercury (MHg) using their respective C_{wtot} values and f_{wc} values.

Variable	Description	Units	Value
C_{wctot}	Total COPC concentration in water column	mg COPC/L water column	
f_{wc}	Fraction of total water body COPC concentration in the water column	unitless	**0 to 1** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-4-16. The following uncertainty is associated with this variable: The default variable values recommended for use in the equation in Table B-4-16 may not accurately represent site-specific water body conditions. However, the ranges of several variables—including d_{bs}, C_{BS}, and θ_{sw}—is relatively narrow. Therefore, the uncertainty is expected to be relatively small. Other variables, such as d_{wc} and d_z, can be reasonably estimated on the basis of generally available information. The largest degree of uncertainty may be introduced by the default medium specific *OC* content values. *OC* content values are often not readily available and can vary widely for different locations in the same medium. Therefore, default values may not adequately represent site-specific conditions.

TOTAL WATER COLUMN CONCENTRATION (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
C_{wtot}	Total waterbody COPC concentration including water column and bed sediment	mg COPC/L water body (or g COPC/m^3 water body)	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-4-15. The following uncertainty is associated with this variable: The default variable values recommended for use in the equation in Table B-4-15 may not accurately represent site--specific water body conditions. The degree of uncertainty associated with variables Vf_x, A_w, d_w, and d_{bs} is expected to be limited either because the probable ranges for variables are narrow or information allowing accurate estimates is generally available. Uncertainty associated with f_{wc} is largely the result of water body associated with default *OC* content values, and may be significant in specific instances. Uncertainties associated with the total COPC load into water body (L_t) and overall total water body COPC dissipation rate constant (k_{wt}) may also be significant in some instances because of the summation of many variable-specific uncertainties.
d_{wc}	Depth of water column	m	**Varies** This variable is site-specific. The following uncertainty is associated with this variable: Use of default values for depth of water column, d_{wc}, may not accurately reflect site-specific water body conditions. Therefore, use of default values may contribute to the under- or overestimation of C_{wctot}. However, the degree of uncertainty associated with this variable is expected to be limited, because information regarding this variable is generally available.
d_{bs}	Depth of upper benthic sediment layer	m	**0.03** This variable is site-specific. U.S. EPA OSW recommends a default upper-benthic sediment depth of 0.03 meters, which is based on the center of a range cited by U.S. EPA (1993a) and U.S. EPA (1993b) This value is consistent with U.S. EPA (1994) and NC DEHNR (1997). The following uncertainty is associated with this variable: The recommended default value for depth of upper benthic sediment layer, d_{bs}, may not accurately represent site-specific water body conditions. Therefore, use of this default value may contribute to the under- or overestimation of C_{wctot}. However, the degree of uncertainty associated with this variable is expected to be limited because of the narrow recommended range.

TABLE B-4-23

TOTAL WATER COLUMN CONCENTRATION (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

REFERENCES AND DISCUSSION

NC DEHNR. 1997. *Final NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is cited as one of the sources of the range of d_{bs} values. This document cites U.S. EPA (1993a) as its source.

U.S. EPA. 1993a. *Addendum: Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Working Group Recommendations. Office of Solid Waste and Office of Research and Development. Washington, D.C. September 24.

This document is cited by U.S. EPA (1994) and NC DEHNR (1997) as one of the sources of the ranges of d_{bs} values. No original source of this range was identified.

U.S. EPA. 1993b. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, D.C. November.

This document states that the upper benthic sediment depth, d_{bs}, representing the portion of the bed in equilibrium with the water column, cannot be precisely specified. However, the document states that values from 0.01 to 0.05 meters would be appropriate.

U.S. EPA. 1994. *Draft Guidance for Performing Screening Level Risk Analysis at Combustor Facilities Burning Hazardous Waste. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facility.* April 15.

This document is cited as one of the reference sources for the default value for depth of upper benthic layer (d_{bs}). The recommended value is the midpoint of an acceptable range. This document cites U.S. EPA (1993a) as the source of its information. The degree of uncertainty associated with the variables d_{wc} and d_{bs} is expected to be minimal either because information for estimating these variables is generally available (d_{wc}) or the probable range for a variable (d_{bs}) is narrow. Uncertainty associated with the variables f_{wc} and C_{wtot} is largely associated with the use of default *OC* content values. Because *OC* content is known to vary widely in different locations in the same medium, use of default medium-specific values can result in significant uncertainty in some instances.

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

TABLE B-4-24

DISSOLVED PHASE WATER CONCENTRATION
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Description

This equation calculates the concentration of COPC dissolved in the water column. Uncertainties associated with this equation include the following:

(1) The variables in the equation in Table B-4-24 are site-specific. Therefore, the use of default values rather than site-specific values, for any or all of these variables, will contribute to the under- or overestimation of C_{dw}. The degree of uncertainty associated with *TSS* is expected to be relatively small, because information regarding reasonable site-specific values for this variable are generally available or it can be easily measured. On the other hand, the uncertainty associated with the variables C_{wctot} and Kd_{sw} is associated with estimates of *OC* content. Because *OC* content values can vary widely for different locations in the same medium, using default *OC* values may result in significant uncertainty in specific cases.

Equation

$$C_{dw} = \frac{C_{wctot}}{1 + Kd_{sw} \cdot TSS \cdot 1 \times 10^{-6}}$$

For mercury modeling, the dissolved phase water concentration is calculated for divalent mercury (Hg^{2+}) and methyl mercury (MHg) using their respective C_{wctot} values and Kd_{sw} values.

Variable	Description	Units	Value
C_{dw}	Dissolved phase water concentration	mg COPC/L water	
C_{wctot}	Total COPC concentration in water column	mg COPC/L water column	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-4-23. The following uncertainty is associated with this variable: All of the variables in the equation in Table B-4-23 are COPC- and site-specific. Therefore, the use of default values rather than site-specific values, for any or all of these variables, will contribute to the under- or overestimation of C_{wctot}. The degree of uncertainty associated with the variables d_{wc} and d_{bs} is expected to be minimal either because information for estimating a variable (d_{wc}) is generally available or because the probable range for a variable (d_{bs}) is narrow. The uncertainty associated with the variables f_{wc} and C_{wtot} is associated with estimates of Organic Carbon, *OC*, content. Because *OC* content values can vary widely for different locations in the same medium, using default *OC* values may result in significant uncertainty in specific cases.

TABLE B-4-24

DISSOLVED PHASE WATER CONCENTRATION (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
Kd_{sw}	Suspended sediments/surface water partition coefficient	L water/kg suspended sediment	**Varies** This variable is COPC-specific. Discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: Values contained in Appendix A-3 for Kd_{sw} are based on default *OC* content values for surface water and soil. Because *OC* content can vary widely for different locations in the same medium, the uncertainty associated with estimated Kd_{sw} values based on default *OC* content values may be significant in specific cases.
TSS	Total suspended solids concentration	mg/L	**2 to 300** This variable is site-specific. U.S. EPA recommends the use of site- and waterbody specific measured values, representative of long-term average annual values for the water body of concern (see Chapter 5). A value of 10 mg/L was cited by NC DEHNR (1997), U.S. EPA (1993a), and U.S. EPA (1993b) in the absense of site-specific measured data. The following uncertainty is associated with this variable: Limitation on measured data used for determining a water body specific total suspended solids (*TSS*) value may not accurately reflect site- and water body-specific conditions long term. Therefore, the *TSS* value may contribute to the under-or overestimation of f_{wc}.
1×10^{-6}	Units conversion factor	kg/mg	

TABLE B-4-24

DISSOLVED PHASE WATER CONCENTRATION
(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

(Page 3 of 3)

REFERENCES AND DISCUSSION

NC DEHNR. 1997. *Final NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is cited as one of the sources of the range of Kd_s values and the *TSS* value of 10. This document cites (1) U.S. EPA (1993a) and U.S. EPA (1993b) as its sources of information regarding *TSS*, and (2) RTI (1992) as its source regarding Kd_s.

U.S. EPA. 1993a. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Working Group Recommendations. Office of Solid Waste and Office of Research and Development. Washington, D.C. September 24.

This document is cited by U.S. EPA (1994) and NC DEHNR (1997) as one of the sources of the range of Kd_s value and the assumed *OC* value of 0.075 for surface water. The generic equation for calculating partition coefficients (soil, surface water, and bed sediments) is as follows: $Kd_{ij} = K_{ocj} * OC_i$. K_{oc} is a chemical-specific value; however, *OC* is medium-specific. The range of Kd_s values was based on an assumed *OC* value of 0.01 for soil. Therefore, the Kd_{sw} values were estimated by multiplying the Kd_s values by 7.5, because the *OC* value for surface water is 7.5 times greater than the *OC* value for soil. This document is also cited by U.S. EPA (1994) and NC DEHNR (1997) as the source of the recommended *TSS* value.

U.S. EPA. 1993b. *Addendum: Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. November.

This document is cited by U.S. EPA (1994) and NC DEHNR (1997) as one of the sources of the range of Kd_s value and the assumed *OC* value of 0.075 for surface water. The generic equation for calculating partition coefficients is as follows: $Kd_{ij} = K_{ocj} \cdot OC_i$. K_{oc} is a chemical-specific value; however, *OC* is medium-specific. The range of Kd_s values was based on an assumed *OC* value of 0.01 for soil. Therefore, the Kd_{sw} values were estimated by multiplying the Kd_s values by 7.5, because the *OC* value for surface water is 7.5 times greater than the *OC* value for soil. This document is also cited by U.S. EPA (1994) and NC DEHNR (1997) as the source of *TSS* values.

U.S. EPA. 1994. *Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Waste. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* April 15.

This document is cited as one of the sources of the range of Kd_s values, citing RTI (1992) as its source of information.

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

COPC CONCENTRATION SORBED TO BED SEDIMENT (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Description

This equation calculates the concentration of COPCs sorbed to bed sediments.

Uncertainties associated with this equation include the following:

(1) The default variable values recommended for use in the equation in Table B-4-25 may not accurately represent site-specific water body conditions. The degree of uncertainty associated with variables θ_{bs}, C_{BS}, d_{wc}, and d_{bs} is expected to be limited either because the probable ranges for these variables are narrow or because information allowing reasonable estimates is generally available.

(2) Uncertainties associated with variables f_{bs}, C_{wtot} and Kd_{bs} are largely associated with the use of default *OC* content values in their calculation. The uncertainty may be significant in specific instances, because *OC* content is known to vary widely in different locations in the same medium.

Equation

$$C_{sb} = f_{bs} \cdot C_{wtot} \cdot \frac{Kd_{bs}}{\theta_{bs} + Kd_{bs} \cdot C_{BS}} \cdot \frac{d_{wc} + d_{bs}}{d_{bs}}$$

For mercury modeling, the COPC concentration sorbed to bed sediment is calculated for divalent mercury (Hg^{2+}) and methyl mercury (MHg) using their respective C_{wtot} values; f_{bs} values; and Kd_{bs} values.

Variable	Description	Units	Value
C_{sb}	Concentration sorbed to bed sediment	mg COPC/kg sediment	
f_{bs}	Fraction of total water body COPC concentration that occurs in the benthic sediment	unitless	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-4-16. The following uncertainty is associated with this variable: The default values for the variables in the equation in Table B-4-16 may not accurately represent site- and water body-specific conditions. However, the range of several variables—including d_{bs}, C_{BS}, and θ_{bs}—is relatively narrow. Other variables, such as d_{wc} and d_z, can be reasonably estimated on the basis of generally available information. The largest degree of uncertainty may be introduced by the default medium-specific *OC* content values. Because *OC* content values may vary widely in different locations in the same medium, by using default values may result in significant uncertainty in specific cases.

COPC CONCENTRATION SORBED TO BED SEDIMENT (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
C_{wtot}	Total water body concentration including water column and bed sediment	mg COPC/L water body (or g COPC/cm^3 water body)	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-4-15. The following uncertainty is associated with this variable: (1) The default variable values recommended for use in the equation in Table B-4-15 may not accurately represent site--specific water body conditions. The degree of uncertainty associated with variables Vf_x, A_w, d_{wc}, and d_{bs} is expected to be limited either because the probable ranges for these variables are narrow or information allowing reasonable estimates is generally available. (2) Uncertainty associated with f_{wc} is largely the result of uncertainty associated with default *OC* content values and may be significant in specific instances. Uncertainties associated with the variable L_T and K_{wt} may also be significant because of the summation of many variable-specific uncertainties.
Kd_{bs}	Bed sediment/sediment pore water partition coefficient	L water/kg bed sediment (or cm^3 water/g bed sediment)	**Varies** This variable is COPC-specific. Discussion of this variable and COPC-specific values are presented in Appendix A-3. The following uncertainty is associated with this variable: The default Kd_{bs} values in Appendix A-3 are based on default *OC* content values for sediment and soil. Because medium-specific *OC* content may vary widely at different locations in the same medium, the uncertainty associated with Kd_{bs} values calculated by using default *OC* content values may be significant in specific instances.
θ_{bs}	Bed sediment porosity	unitless ($L_{pore\ volume}/L_{sediment}$)	**0.6** This variable is site-specific. U.S. EPA OSW recommends a default bed sediment porosity of 0.6 (by using a C_{BS} value of 1 g/cm^3 and a solids density (ρ_s) value of 2.65 kg/L), calculated by using the following equation (U.S. EPA 1993a): $\theta_{bs} = 1 - C_{BS}/\rho_s$ This also is consistent with U.S. EPA (1993b), U.S. EPA (1994), and NC DEHNR (1997). The following uncertainty is associated with this variable: To the extent that the recommended default values of C_{BS} and ρ_s do not accurately represent site- and water body-specific conditions, θ_{bs} will be under- or overestimated to some degree. However, the degree of uncertainty is expected to be minimal, based on the narrow range of recommended values.

TABLE B-4-25

COPC CONCENTRATION SORBED TO BED SEDIMENT (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

Variable	Description	Units	Value
C_{BS}	Bed sediment concentration (or bed sediment bulk density)	g/cm^3	**1.0** This variable is site-specific. U.S. EPA OSW recommends a default value of 1.0, consistent with U.S. EPA (1993a), which states that this value should be reasonable for most applications. No reference is cited for this recommendation. This is also consistent with U.S. EPA (1993b), U.S. EPA (1994), and NC DEHNR (1997). The following uncertainty is associated with this variable: The recommended default value for θ_{bs} may not accurately represent site- and water body-specific conditions. Therefore, the variable C_{sb} may be under- or overestimated to a limited degree, as indicated by the narrow range of recommended values.
d_{wc}	Depth of water column	m	**Varies** This variable is site-specific. The following uncertainty is associated with this variable: Use of d_{wc} values may not accurately reflect site-specific conditions. Therefore, use of these values may contribute to the under- or overestimation of the variable C_{sb}. However, the degree of uncertainty is expected to be minimal, because resources allowing reasonable water body-specific estimates of d_{wc} are generally available.
d_{bs}	Depth of upper benthic sediment layer	m	**0.03** This variable is site-specific. U.S. EPA OSW recommends a default upper-benthic sediment depth of 0.03 meters, which is based on the center of a range cited by U.S. EPA (1993b). This value is consistent with U.S. EPA (1994) and NC DEHNR (1997). The following uncertainty is associated with this variable: Use of default d_{bs} values may not accurately reflect site-specific conditions. Therefore, use of these values may contribute to the under- or overestimation of the variable C_{sb}. However, the degree of uncertainty is expected to be small, based on the narrow recommended range of default values.

REFERENCES AND DISCUSSION

NC DEHNR. 1997. *Final NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is cited as one of the sources of the range of Kd_s values and an assumed OC value of 0.04 for sediment. This document cites RTI (1992) as its source of information regarding Kd_s values. This document is also cited as one of the reference source documents for the default value for bed sediment porosity(θ_{sw}). This document cites U.S. EPA (1993a; 1993b) as its source of information. This document is also cited as one of the reference source documents for the default value for depth of the upper benthic layer. The default value is the midpoint of an acceptable range. This document cites U.S. EPA (1993a) and U.S. EPA (1993b) as its source of information for the range of values for the depth of the upper benthic layer. This document is also cited as one of the reference source documents for the default bed sediment concentration (C_{BS}). This document cites U.S. EPA (1993a; 1993b) as its source.

U.S. EPA. 1993a. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, D.C. November 1993.

This document is cited by U.S. EPA (1994) and NC DEHNR (1997) as one of the sources of the range of Kd_s values and an assumed OC value of 0.04 for sediment. The generic equation for calculating partition coefficients (soil, surface water, and bed sediments) is as follows: $Kd_{ij} = K_{oc} \cdot OC_i$. K_{oc} is a chemical-specific value; however, OC is medium-specific. The range of Kd_s values was based on an assumed OC value of 0.01 for soil. Therefore, the Kd_{bs} value was estimated by multiplying the Kd_s values by 4, because the OC value for sediment is four times greater than the OC value for soil. This document is also cited as the source of the equation for calculating bed sediment porosity (θ_{sw}). No source of this equation was identified. This document was also cited as the source for the range of the bed sediment concentration (C_{BS}). No source of this range was identified.

U.S. EPA. 1993b. *Addendum: Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* Working Group Recommendations. Office of Solid Waste and Office of Research and Development. Washington, D.C. September 24.

This document is cited by NC DEHNR (1997) and U.S. EPA (1994) as the source of the default bed sediment porosity value (θ_{sw}), the default bed sediment concentration value (C_{BS}), and the range for depth of upper benthic layer (d_{bs}) values.

U.S. EPA. 1994. *Draft Guidance for Performing Screening Level Risk Analysis at Combustor Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* April 15.

This document is cited as one of the sources of the range of Kd_s values and an assumed OC value of 0.04 for sediment. This document cites RTI (1992) as its source of information regarding Kd_s values. This document is cited as one of the reference source documents for the default value for bed sediment porosity (θ_{sw}). This document cites U.S. EPA (1993a; 1993b) as its source. This document is also cited as one of the reference source documents for the default value for depth of upper benthic layer (d_{bs}). The default value is the midpoint of an acceptable range. This document cites U.S. EPA (1993a) and U.S. EPA (1993b) as its source of information for the range of values for the depth of the upper benthic layer. This document is also cited as one of the reference source documents for the default bed sediment concentration (C_{BS}). This document cites U.S. EPA (1993b) as its source.

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

TABLE B-4-26

FISH CONCENTRATION FROM BIOCONCENTRATION FACTORS USING DISSOLVED PHASE WATER CONCENTRATION (CONSUMPTION OF FISH EQUATIONS)

Description

This equation calculates fish concentration, from dissolved COPCs, by using a bioconcentration factor. Uncertainty associated with this equation include the following:

The calculation of C_{dw} is dependent on default values for two variables C_{wctot} and Kd_{sw}. Values for these two variables are, in turn, dependent on default medium-specific *OC* content values. Because *OC* content can vary widely at different locations in the same medium, significant uncertainty may be associated with C_{wctot} and Kd_{sw} and, in turn, C_{dw} in specific instances.

Equation

$$C_{fish} = C_{dw} \cdot BCF_{fish}$$

Variable	Description	Units	Value
C_{fish}	Concentration of COPC in fish	mg COPC/kg FW tissue	
C_{dw}	Dissolved phase water concentration	mg COPC/L	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-4-24. Uncertainties associated with this variable include the following: (1) The variables in the equation in Table B-4-24 are site-specific. Therefore, the use of default values rather than site-specific values, for any or all of these variables, will contribute to the under- or overestimation of C_{dw}. The degree of uncertainty associated with *TSS* is expected to be relatively small, because information regarding reasonable site-specific values for this variable is generally available or can be easily measured. (2) The uncertainty associated with the variables C_{wctot} and Kd_{sw} is dependent on estimates of *OC* content. Because *OC* content values can vary widely for different locations in the same medium, the uncertainty associated with using different *OC* content values may be significant in specific cases.

FISH CONCENTRATION FROM BIOCONCENTRATION FACTORS USING DISSOLVED PHASE WATER CONCENTRATION (CONSUMPTION OF FISH EQUATIONS)

Variable	Description	Units	Value
BCF_{fish}	Bioconcentration factor for COPC in fish	unitless ([mg COPC/kg FW tissue]/[mg COPC/kg feed])	**Varies** This variable is COPC-specific. Discussion of this variable and COPC-specific values are presented in Appendix A-3. Values As explained in Appendix A-3, U.S. EPA OSW recommends using *BCFs* for organic COPCs with log K_{ow} less than 4.0 and *BAFs* (rather than *BCFs*) for organic COPCs with log K_{ow} of 4.0 or greater. For organics with a log K_{ow} value of less than 4.0 and all metals (except lead and mercury), values were obtained from U.S. EPA (1998) or, when measured values were not available, derived from the correlation equation presented by Lyman, Reehl, and Rosenblatt (1982). The following uncertainty is associated with this variable: The COPC-specific *BCF* values may not accurately represent site-specific water body conditions, because estimates of *BCFs* and *BAFs* can vary, based on experimental conditions.

REFERENCES AND DISCUSSION

Ellgenhausen, H. J., A. Guth, and H.O. Esser. 1980. "Factors Determining the Bioaccumulation Potential of Pesticides in the Individual Compartments of Aquatic Food Chains." *Ecotoxicology Environmental Safety.* Vol. 4. P. 134.

*BCF*s for pesticides and polycyclic aromatic hydrocarbons (PAHs) with log K_{ow} less than 5.5 were apparently calculated by using the following equation derived for pesticides from this document:

$$\log BCF = 0.83 \cdot \log K_{ow} - 1.71$$

where

BCF = Bioconcentration factor for COPC in fish(unitless)
K_{ow} = Octanol-water partition coefficient (unitless)

Lyman, W.J., W.F. Reehl, and D.H. Rosenblatt. 1982. *Handbook of Chemical Property Estimation Methods: Environmental Behavior of Organic Compounds.* McGraw-Hill Book Company. New York, New York.

NC DEHNR. 1997. *Final NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document cites the following documents as its sources of the equations used to calculate *BCF*s fish:

Ogata, M.K., Y. Ogino Fijusaw, and E. Mano. 1984. "Partition Coefficients as a Measure of Bioconcentration Potential of Crude Oil Compounds in Fish and Shellfish." *Bulletin of Environmental Contaminant Toxicology.* Vol. 33. P. 561.

*BCF*s for compounds with $\log K_{ow}$ less than 5.5 were calculated by using the following equation derived for aromatic compounds from this document:

$$\log BCF = 0.71 \cdot \log K_{ow} - 0.92$$

where

BCF = Bioconcentration factor for COPC in fish (unitless)
K_{ow} = Octanol-water partition coefficient (unitless)

U.S. EPA. 1994. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

See the note for NC DEHNR (1997).

U.S. EPA. 1995. *Review Draft Development of Human-Health Based and Ecologically - Based Exit Criteria for the Hazardous Waste Identification Project. Volumes I and II.* Office of Solid Waste. March 3.

This document recommends that the following references be used:

- *BCFs* for organic COPCs with log K_{ow} less than 4.0 should be based on equations presented in Thomann, R.V. 1989. "Bioaccumulation Model of Organic Chemical Distribution in Aquatic Food Chains." *Environmental Science and Technology*-23(b): 699-707.
- *BAFs* for organic COPCs with log K_{ow} greater than or equal to 4.0 and less than 6.5 are estimated on the basis of models presented in Thomann (1989) - see above - for the limnetic ecosystem, or for the littoral ecosystem, based on the following document:
    - Thomann, R.V., J.P. Connolly, and T.F. Parkerton. 1992. "An Equilibrium Model of Organic Chemical Accumulation in Aquatic Food Webs with Sediment Interaction." *Environmental Toxicology and Chemistry.* 11:615-629.
- For organics with log K_{ow} greater than or equal to 6.5, a default *BAF* of 1,000 was assumed on the basis of an analysis of available data on polycyclic aromatic hydrocarbons (PAH), and the following document:
    - Stephan, C.E. et al. 1993. "*Derivation of Proposed Human Health and Wildlife Bioaccumulation Factors for the Great Lake Initiative.*" Office of Research and Development. U.S. EPA Research Laboratory. PB93-154672. Springfield, Virginia.
- *BCFs* for inorganics were obtained from various literature sources and the AQUIRE electronic database.

All *BCFs* and *BAFs* were corrected to 5 percent lipid, reflecting a typical value for a fish fillet.

U.S. EPA. 1998. *Screening Level Ecological Risk Assessment Protocol for Hazardous Waste Combustion Facilities.* Interim Final. Office of Solid Waste. February.

TABLE B-4-27

FISH CONCENTRATION FROM BIOACCUMULATION FACTORS USING DISSOLVED PHASE WATER CONCENTRATION (CONSUMPTION OF FISH EQUATIONS)

Description

This equation calculates fish concentration from dissolved COPC concentration by using a bioaccumulation factor. Uncertainty associated with this equation include the following:

The calculation of C_{dw} is dependent on default values for variables F_{water} and C_{wtot}. Values for these two variables are, in turn, dependent on default medium-specific *OC* content values. Because *OC* content can vary widely at different locations in the same medium, significant uncertainty may be associated with F_{water} and C_{wtot}, and, in turn, C_{wt} in specific instances.

Equation

$$C_{fish} = C_{dw} \cdot BAF_{fish}$$

For mercury modeling, the concentration of COPC in fish from total water column concentration is calculated for methyl mercury (MHg) by applying the concentration of Hg^{2+} and MHg as shown in the following equation:

$$C_{fish_{(MHg)}} = C_{dw_{(Hg^{2+} + MHg)}} \cdot BAF_{fish_{(MHg)}}$$

Variable	Description	Units	Value
C_{fish}	Concentration of COPC in fish	mg COPC/kg FW tissue	

TABLE B-4-27

FISH CONCENTRATION FROM BIOACCUMULATION FACTORS USING DISSOLVED PHASE WATER CONCENTRATION (CONSUMPTION OF FISH EQUATIONS)

Variable	Description	Units	Value
C_{dw}	Dissolved phase water concentration	mg COPC/L	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-4-24. Uncertainties associated with this variable include the following: (1) The variables in the equation in Table B-4-24 are site-specific. Therefore, the use of default values rather than site-specific values, for any or all of these variables, will contribute to the under- or overestimation of C_{dw}. The degree of uncertainty associated with *TSS* is expected to be relatively small, because information regarding reasonable site-specific values for this variable is generally available or can be easily measured. (2) The uncertainty associated with the variables C_{wctot} and Kd_{sw} is dependent on estimates of *OC* content. Because *OC* content values can vary widely for different locations in the same medium, the uncertainty associated with using different *OC* content values may be significant in specific cases.
BAF_{fish}	Bioaccumulation factor for COPC in fish	L/kg FW tissue	**Varies** This variable is COPC-specific. Discussion of this variable and COPC-specific values are presented in Appendix A-3. As discussed in Appendix A-3, BAF_{fish} values were adjusted for dissolved water concentrations. For all organics with a log K_{ow} greater than or equal to 4.0, BAFs were obtained from U.S. EPA (1998), which cites U.S. EPA (1995a), U.S. EPA (1995b), and U.S. EPA (1994b). BAF_{fish} value for lead was obtained as a geometric mean from various literature sources described in U.S. EPA (1998). Elemental mercury is not expected to deposit significantly onto soils and surface water; therefore, it is assumed that no transfer of elemental mercury to fish. All mercury in fish is assumed to exist or be converted to methyl mercury (organic) form after uptake into the fish tissue. For this HHRAP, the BAF_{fish} value for methyl mercury was obtained from U.S. EPA (1997) for a trophic level 4 fish. The following uncertainty is associated with this variable: The COPC-specific *BAF* values may not accurately represent site-specific water body conditions, because estimates of *BAFs* can vary, based on experimental conditions.

REFERENCES AND DISCUSSION

NC DEHNR. 1997. *Final NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document cites the following documents as its sources of information regarding *BAF*s:

U.S. EPA. 1993. "*Derivation of Proposed Human Health and Wildlife Bioaccumulation Factors for the Great Lakes Initiative.*" Office of Research and Development, U.S. Environmental Research Laboratory. Duluth, Minnesota. March.

This study presents three methods for estimating *BAFs*, in the following order of preference (first to last): (1) measured *BAF*; (2) measured *BCF* multiplied by a food-chain multiplier estimated from log K_{ow}; and (3) *BAF* estimated from log K_{ow}.

U.S. EPA 57 Federal Register 20802. 1993. "Proposed Water Quality Guidance for the Great Lakes System." April 16.

This document recommends that *BAF*s be used for compounds with a log K_{ow} greater than 5.5.

U.S. EPA. 1994. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

See the note for NC DEHNR (1997).

U.S. EPA. 1995a. *Review Draft Development of Human Health-Based and Ecologically-Based Exit Criteria for the Hazardous Waste Identification Project. Volumes I and II.* Office of Solid Waste. March 3.

This document recommends that the following references be used.

- *BAFs* for organic COPCs with log K_{ow} should be calculated from the following references
- *BAFs* for organic COPCs with log K_{ow} greater than 4.0 but less than 6.5 should be calculated from the following references for the limetic ecosystem and the litteral ecosystem, respectively.

    - Thomann, R.V. 1989. "Bioaccumulation Model of Organic Chemical Distribution in Aquatic Food Chains." *Environmental Science and Technology.* 23(6):699-707.
    - Thomann, R.V., J.P. Connolly, and T.F. Parkerton. 1992. "An Equilibrium Model of Organic Chemical Accumulation in Aquatic Food Webs with Sediment Interaction." *Environmental Toxicology and Chemistry.* 11:6115-629.

- *BAFs* for compounds with log K_{ow} greater than 6.5 were allowed to equal 1,000, based on an analysis of available data on PAHs and the following document:

    - Stephan, C.E. et al. 1993. "Derivation of Proposed Human Health and Wildlife Bioaccumulation Factors for the Great Lakes Initiative." Office of Research and Development, U.S. Environmental Research Laboratory. PB93-154672. Springfield, Virigina.

All *BAFs* were corrected to 5 percent lipid, reflecting a typical value for a fish fillet.

TABLE B-4-27

FISH CONCENTRATION FROM BIOACCUMULATION FACTORS USING DISSOLVED PHASE WATER CONCENTRATION (CONSUMPTION OF FISH EQUATIONS)

U.S. EPA. 1995b. *Great Lakes Water Quality Initiative. Technical Support Document for the Procedure to Determine Bioaccumulation Factors.* Office of Water. EPA-820-B-95-005. March.

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

U.S. EPA. 1998. *Screening Level Ecological Risk Assessment Protocol for Hazardous Waste Combustion Facilities.* Draft Interim Final. Office of Solid Waste. February.

TABLE B-4-28

FISH CONCENTRATION FROM BIOTA-TO-SEDIMENT ACCUMULATION FACTORS USING COPC SORBED TO BED SEDIMENT (CONSUMPTION OF FISH EQUATIONS)

Description

This equation calculates fish concentration from bed sediment concentration, by using a biota-to-sediment accumulation factor (*BSAF*). Uncertainties associated with this equation include the following:

(1) Calculation of C_{sb} is largely dependent on default medium-specific *OC* content values. Because *OC* content can vary widely within a medium, significant uncertainty may be associated with estimates of C_{sb} in specific instances.
(2) Lipid content varies between different species of fish. Therefore, use of a default f_{lipid} value results in a moderate degree of uncertainty.
(3) Some species of fish have limited, if any, contact with water body sediments. Therefore, use of *BSAFs* to estimate the accumulation of COPCs in these species may be signficantly uncertain.

Equation

$$C_{fish} = \frac{C_{sb} \cdot f_{lipid} \cdot BSAF}{OC_{sed}}$$

Variable	Description	Units	Value
C_{fish}	Concentration of COPC in fish	mg COPC/kg FW tissue	
C_{sb}	Concentration of COPC sorbed to bed sediment	mg COPC/kg bed sediment	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-4-25. Uncertainties associated with this variable include the following: (1) The default variable values recommended for use in the equation in Table B-4-25 may not accurately represent site-specific water body conditions. The degree of uncertainty associated with variables θ_{bs}, *TSS*, d_{wc}, and d_{bs} is expected to be limited either because the probable ranges for these variables are narrow or information allowing reasonable estimates is generally available. (2) Uncertainty associated with variables f_{bs}, C_{wtot}, and Kd_{bs} is largely associated with the use of default *OC* content values. Because *OC* content is known to vary widely in different locations in the same medium, use of default medium-specific values can result in significant uncertainty in some instances.

TABLE B-4-28

FISH CONCENTRATION FROM BIOTA-TO-SEDIMENT ACCUMULATION FACTORS USING COPC SORBED TO BED SEDIMENT (CONSUMPTION OF FISH EQUATIONS)

Variable	Description	Units	Value
f_{lipid}	Fish lipid content	unitless	**0.07** U.S. EPA OSW recommends this default value, consistent with U.S. EPA (1994a), U.S. EPA (1993), and U.S. EPA (1994b). This value was originally cited by Cook, Duehl, Walker, and Peterson (1991). The following uncertainty is associated with this variable: (1) Lipid content may vary between different species of fish. Therefore, the use of a default f_{lls} value may result in under- or overestimation of C_{fish}.
BSAF	Biota-to-sediment accumulation factor	unitless ([mg COPC/kg lipid tissue]/[mg COPC/kg sediment])	**Varies** This variable is COPC-specific. Discussion of this variable and COPC-specific values are presented in Appendix A-3. These factors are applied only to PCDDs, PCDFs, and polychlorinated biphenyls (PCBs), consistent with NC DEHNR (1997); U.S. EPA (1992), U.S. EPA (1993), U.S. EPA (1994), and U.S. EPA (1995). Uncertainty is associated with this variable: The greatest uncertainty associated with using *BSAFs* is that some species of fish have limited, if any, contact with water body sediments. Any accumulation of compounds into the tissue of these fishes is almost entirely the result of contact with surface water. Therefore, use of *BSAFs* to estimate COPC accumulation in these species may be uncertain.
OC_{sed}	Fraction of organic carbon in bottom sediment	unitless	**0.04** This variable is site-specific. U.S. EPA OSW recommends a default value of 0.04, the midpoint of the range (0.03 to 0.05), if site-specific information is not available. This is consistent with other U.S. EPA (1993 and 1994b) and NC DEHNR (1997) guidance. The following uncertainty is associated with this variable:: The recommended OC_{sed} value may not accurately represent site-specific water body conditions. However, as indicated by the probable range of values for this parameter, any uncertainty is expected to be limited in most cases.

FISH CONCENTRATION FROM BIOTA-TO-SEDIMENT ACCUMULATION FACTORS USING COPC SORBED TO BED SEDIMENT (CONSUMPTION OF FISH EQUATIONS)

REFERENCES AND DISCUSSION

Cook, P.M., D.W. Duehl, M.K. Walker, and R.E. Peterson. 1991. *Bioaccumulation and Toxicity of TCDD and Related Compounds in Aquatic Ecosystems.* In Gallo, M.A., R.J. Scheuplein, and K.A. Van Der Heijden (eds). *Banbury Report 35: Biological Basis for Risk Assessment of Dioxins and Related Compounds.* Cold Spring Harbor Laboratory Press. 0-87969-235-9/91.

This document is cited by U.S. EPA (1992), U.S. EPA (1993), and U.S. EPA (1994) as the source of the fish lipid content value.

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is cited as one of the reference source documents for biota-to-sediment factors for PCBs and dioxins. This document cites U.S. EPA (1992) as its source. This document is also cited as one of the reference documents for the default value for fraction *OC* in bottom sediment. The default value is the midpoint of the range obtained from U.S. EPA (1993). No source of this recommendation was identified.

This document is cited as one of the reference source documents for the fish lipid content value. The document cites Cook, Duehl, Walker, and Peterson (1991) as its original source of information. This document is also cited by U.S. EPA (1994) and NC DEHNR (1997) as the source of the *BSAF*s. *BSAF* values from this document were either measured values or estimates based on a whole fish lipid content of 7 percent. Specifically, *BSAF* values from this document must be evaluated because of the difficult experimental methods used to derive them.

U.S. EPA. 1993. *Addendum to the Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions.* External Review Draft. Office of Research and Development. Washington, D.C. November.

This document is cited as one of the reference source documents for the fish lipid content value. The document cites Cook, Duehl, Walker, and Peterson (1991) as its original source of information. This document is also cited for the range for fraction *OC* in bottom sediment. No reference document was cited for this range. Finally, this document recommends using biota-sediment accumulation factors (*BSAF*) for dioxin-like, compounds, including PCBs, because of their lipophilic nature.

U.S. EPA. 1994a. *Estimating Exposure to Dioxin-Like Compounds. Volume III: Site-specific Assessment Procedures.* External Review Draft. Office of Research and Development. Washington. D.C. EPA/600/6-88/005Cc. June.

U.S. EPA. 1994b. *Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* April 15.

This document is cited as one of the reference source documents for the fish lipid content value. The document cites Cook, Duehl, Walker, and Peterson (1991) as its original source of information. This document is also cited as one of the reference source documents for biota-to-sediment factors for PCBs and dioxins. This document cites U.S. EPA (1992) as its source of information. This document is also cited as one of the reference documents for the default fraction *OC* in bottom sediment value. The default value is the midpoint of the range obtained from U.S. EPA (1993). No source of this recommendation was identified.

U.S. EPA. 1995. *Review Draft Development of Human Health-Based and Ecologically-Based Exit Criteria for the Hazardous Waste Identification Project. Volumes I and II.* Office of Solid Waste. March 3.

This document states that *a BSAF* is a more reliable measure of bioaccumulation potential because of the analytical difficulties in measuring dissolved concentrations in surface water. This document also recommends using *BSAFs* for 2,3,7,8-TCDD and PCBs..

TABLE B-5-1

AIR CONCENTRATION
(DIRECT INHALATION EQUATION)

Description

This equation calculates the air concentration of a COPC based on the fraction in vapor phase and the fraction in particle phase.

Uncertainties associated with this equation include the following:

(1) Most of the uncertainties associated with the variables in this equation—specifically, those associated with variables *Q*, *Cyv*, and *Cyp*—are site-specific.

(2) In calculation of F_v, the equation assumes a default S_T value for background plus local sources, rather than an S_T value for urban sources. If a specific site is located in an urban area, the use of the latter S_T value may be more appropriate. Specifically, the S_T value for urban sources is about one order of magnitude greater than the S_T value for background plus local sources and would result in a lower calculated F_v value; however, the F_v value is likely to be only a few percent lower.

Equation

For all COPCs (except mercury)

$$C_a = Q \cdot \left[F_v \cdot Cyv + (1.0 - F_v) \cdot Cyp \right]$$

Air concentration is calculated using (1) 0.002Q and F_v = 1.0 for elemental mercury (Hg^0) and (2) 0.48Q and F_v = 0.85 for divalent mercury (Hg^{2+}). Elemental mercury is evaluated only for the inhalation exposure pathway (see discussion in Chapter 2).

$$For\ Hg^0:\ C_a = 0.002Q \cdot \left[F_v \cdot Cyv + (1.0 - F_v) \cdot Cyp \right]$$

$$For\ Hg^{2+}:\ C_a = 0.48Q \cdot \left[F_v \cdot Cyv + (1.0 - F_v) \cdot Cyp \right]$$

Variable	Description	Units	Value
C_a	Air concentration	µg/m³	
Q	COPC-specific emission rate	g/s	**Varies** This variable is COPC- and site-specific. See Chapters 2 and 3 for guidance regarding the calculation of this variable. Uncertainties associated with this variable are COPC- and site-specific.

TABLE B-5-1

AIR CONCENTRATION (DIRECT INHALATION EQUATION)

Variable	Description	Units	Value
F_v	Fraction of COPC air concentration in vapor phase	unitless	**0 to 1** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values is presented in Appendix A-3. This range is based on values presented in Appendix A-3. Values are also presented in U.S. EPA (1994b) and NC DEHNR (1997). F_v was calculated using an equation presented in Junge (1977) for all organic COPCs, including PCDDs and PCDFs. U.S. EPA (1994c) states that $F_v = 0$ for all metals (except mercury). The following uncertainties are associated with this variable: (1) It is based on the assumption of a default, S_T value for background plus local sources, rather than an S_T value for urban sources. If a specific site is located in an urban area, the use of the latter S_T value may be more appropriate. Specifically, the S_T value for urban sources is about one order of magnitude greater than that for background plus local sources, and it would result in a lower calculated F_v value; however, the F_v value is likely to be only a few percent lower. (2) According to Bidleman (1988), the equation used to calculate F_v assumes that the variable *c* (Junge constant) is constant for all chemicals; however, the value of *c* depends on the chemical (sorbate) molecular weight, the surface concentration for monolayer coverage, and the difference between the heat of desorption from the particle surface and the heat of vaporization of the liquid-phase sorbate. To the extent that site- or COPC-specific conditions may cause the value of *c* to vary, uncertainty is introduced if a constant value of *c* is used to calculate F_v.
Cyv	Unitized yearly air concentration from vapor phase	µg-s/g-m^3	**Varies** This variable is COPC- and site-specific and is determined by air dispersion modeling (see Chapter 3). Uncertainties associated with this variable are COPC- and site-specific.
Cyp	Unitized yearly air concentration from particle phase	µg-s/g-m^3	**Varies** This variable is COPC- and site-specific and is determined by air dispersion modeling (see Chapter 3). Uncertainties associated with this variable are COPC- and site-specific.

TABLE B-5-1

AIR CONCENTRATION
(DIRECT INHALATION EQUATION)

REFERENCES AND DISCUSSION

Bidleman, T.F. 1988. "Atmospheric Processes." *Environmental Science and Technology.* Volume 22. Number 4. Pages 361-367.

For discussion, see References and Discussion, Table B-1-1.

Junge, C.E. 1977. *Fate of Pollutants in Air and Water Environments, Part I.* Suffet, I.H., Ed. Wiley. New York. Pages 7-26.

NC DEHNR. 1997. *Final NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document recommends using the equations in Bidleman (1988) to calculate F_v values for all organics other than dioxins (PCDD/PCDFs). However, this document does not present a recommendation for dioxins. This document also states that metals are generally entirely in the particulate phase ($F_v = 0$), except for mercury, which is assumed to be entirely in the vapor phase. The document does not state whether F_v for mercury should be calculated by using the equations in Bidleman (1988).

U.S. EPA. 1994. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document presents F_v values for organic COPCs that range from 0.27 to 1. F_v values for organics other than PCDD/PCDFs are calculated by using the equations presented in Bidleman (1988). The F_v value for PCDD/PCDFs is assumed to be 0.27. This value represents dioxin TEQs by weighting data for all dioxin and furan congeners with nonzero TEFs. This document presents F_v values for most inorganic COPCs equal to 0, based on the assumption that these COPCs are nonvolatile and assumed to be 100 percent in the particulate phase and 0 percent in the vapor phase.

U.S. EPA. 1997. *Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment.* Office of Air Quality and Planning and Standards and Office of Research and Development. EPA 452/R-97-005. December.

TABLE B-6-1

ACUTE AIR CONCENTRATION EQUATION
(ACUTE EQUATION)

Description

This equation calculates the total air concentration of a COPC (hourly) based on the fraction in vapor phase and the fraction in particle phase.

Uncertainties associated with this equation include the following:

(1) Most of the uncertainties associated with the variables in this equation—specifically, those associated with variables Q, Chv, and Chp—are site-specific.

(2) In calculation of F_v, the equation assumes a default S_T value for background plus local sources, rather than an S_T value for urban sources. If a specific site is located in an urban area, the use of the latter S_T value may be more appropriate. Specifically, the S_T value for urban sources is about one order of magnitude greater than the S_T value for background plus local sources and would result in a lower calculated F_v value; however, the F_v value is likely to be only a few percent lower.

Equation

For all COPCs (except mercury)

$$C_{acute} = Q \cdot \left[F_v \cdot Chv + (1.0 - F_v) \cdot Chp \right]$$

Acute air concentration is calculated using 0.002Q and $F_v = 1.0$ for elemental mercury (Hg^0). Elemental mercury is the only species of mercury evaluated for the acute inhalation exposure pathway (see discussion in Chapter 2).

$$C_{acute} = 0.48Q \cdot \left[F_v \cdot Chv + (1.0 - F_v) \cdot Chp \right]$$

Variable	Description	Units	Value
C_{acute}	Acute air concentration	µg/m^3	
Q	COPC-specific emission rate	g/s	**Varies** This variable is COPC- and site-specific. See Chapters 2 and 3 for guidance regarding the calculation of this variable. Uncertainties associated with this variable are COPC- and site-specific.

TABLE B-6-1

ACUTE AIR CONCENTRATION EQUATION
(ACUTE EQUATION)

Variable	Description	Units	Value
F_v	Fraction of COPC air concentration in vapor phase	unitless	**0 to 1** This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values is presented in Appendix A-3. This range is based on values presented in Appendix A-3. Values are also presented in U.S. EPA (1994b) and NC DEHNR (1997). F_v was calculated using an equation presented in Junge (1977) for all organic COPCs, including PCDDs and PCDFs. U.S. EPA (1994c) states that $F_v = 0$ for all metals (except mercury). The following uncertainties are associated with this variable: (1) It is based on the assumption of a default, S_T value for background plus local sources, rather than an S_T value for urban sources. If a specific site is located in an urban area, the use of the latter S_T value may be more appropriate. Specifically, the S_T value for urban sources is about one order of magnitude greater than that for background plus local sources, and it would result in a lower calculated F_v value; however, the F_v value is likely to be only a few percent lower. (2) According to Bidleman (1988), the equation used to calculate F_v assumes that the variable c (Junge constant) is constant for all chemicals; however, the value of c depends on the chemical (sorbate) molecular weight, the surface concentration for monolayer coverage, and the difference between the heat of desorption from the particle surface and the heat of vaporization of the liquid-phase sorbate. To the extent that site- or COPC-specific conditions may cause the value of c to vary, uncertainty is introduced if a constant value of c is used to calculate F_v.
Chv	Unitized hourly air concentration from vapor phase	$\mu g\text{-}s/g\text{-}m^3$	**Varies** This variable is COPC- and site-specific and is determined by air dispersion modeling (see Chapter 3). Uncertainties associated with this variable are COPC- and site-specific.
Chp	Unitized hourly air concentration from particle phase	$\mu g\text{-}s/g\text{-}m^3$	**Varies** This variable is COPC- and site-specific and is determined by air dispersion modeling (see Chapter 3). Uncertainties associated with this variable are COPC- and site-specific.

TABLE B-6-1

ACUTE AIR CONCENTRATION EQUATION
(ACUTE EQUATION)

(Page 3 of 3)

REFERENCES AND DISCUSSION

Bidleman, T.F. 1988. "Atmospheric Processes." *Environmental Science and Technology.* Volume 22. Number 4. Pages 361-367.

For discussion, see References and Discussion, Table B-1-1.

Junge, C.E. 1977. *Fate of Pollutants in Air and Water Environments, Part I.* Suffet, I.H., Ed. Wiley. New York. Pages 7-26.

NC DEHNR. 1997. *Final NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document recommends using the equations in Bidleman (1988) to calculate F_v values for all organics other than dioxins (PCDD/PCDFs). However, this document does not present a recommendation for dioxins. This document also states that metals are generally entirely in the particulate phase ($F_v = 0$), except for mercury, which is assumed to be entirely in the vapor phase. The document does not state whether F_v for mercury should be calculated by using the equations in Bidleman (1988).

U.S. EPA. 1994. *Revised Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document presents F_v values for organic COPCs that range from 0.27 to 1. F_v values for organics other than PCDD/PCDFs are calculated by using the equations presented in Bidleman (1988). The F_v value for PCDD/PCDFs is assumed to be 0.27. This value represents dioxin TEQs by weighting data for all dioxin and furan congeners with nonzero TEFs. This document presents F_v values for most inorganic COPCs equal to 0, based on the assumption that these COPCs are nonvolatile and assumed to be 100 percent in the particulate phase and 0 percent in the vapor phase.

U.S. EPA. 1997. "Mercury Study Report to Congress." Volume III. Draft. Office of Air Quality and Planning and Standards and Office of Research and Development. December.

APPENDIX C

RISK CHARACTERIZATION EQUATIONS

Human Health Risk Assessment Protocol

July 1998

APPENDIX C

RISK CHARACTERIZATION EQUATIONS

APPENDIX C

LIST OF VARIABLES

ADD	=	Average daily dose (mg COPC/kg BW-day)
ADD_{infant}	=	Average daily dose for infant exposed to contaminated breast milk (pg [or mg] COPC/kg BW infant/day)
ADD_{mat}	=	Average daily dose, mother (pg COPC/kg BW mother/day)
ADI	=	Average daily COPC intake via inhalation (mg COPC/kg BW-day)
$AHQ_{inh(I)}$	=	Acute hazard quotient for inhalation of COPCs (unitless)
$AIEC$	=	COPC acute inhalation exposure criteria (mg/m^3)
A_I	=	Concentration of COPC *I* in animal tissue *j* (mg COPC/kg FW tissue)
AT	=	Averaging time (yr)
AT_{infant}	=	Averaging time for infant (yr)
BW	=	Body weight (kg)
BW_{infant}	=	Body weight of infant (kg)
C_a	=	Total COPC air concentration (µg/m^3)
C_{acute}	=	Acute air concentration (µg/m^3)
$Cancer\ Risk_I$	=	Individual lifetime risk through indirect exposure to COPC carcinogen *I* (unitless)
$Cancer\ Risk_{inh(I)}$	=	Individual lifetime cancer risk through direct inhalation of COPC carcinogen *I* (unitless)
C_{dw}	=	Dissolved phase water concentration (mg COPC/L water)
C_{fish}	=	Concentration in fish (mg COPC/kg FW tissue)
$C_{milkfat}$	=	Concentration in milk fat of breast milk for a specific exposure scenario (pg [or mg] COPC/kg milk fat)
CR_{ag}	=	Consumption rate of aboveground produce (kg DW plant/kg BW-day)
CR_{bg}	=	Consumption rate of belowground produce (kg DW plant/kg BW-day)
CR_{dw}	=	Consumption rate of drinking water (L water/day)
CR_{fish}	=	Consumption rate of fish (kg/kg BW-day)
CR_j	=	Consumption rate of animal tissue *j* (kg/kg-day FW)
CR_{pp}	=	Consumption rate of protected aboveground produce (kg DW plant/kg BW-day)
CR_{soil}	=	Consumption rate of soil (kg soil/day)
Cs	=	Average soil concentration over exposure duration (mg COPC/kg soil)
ED	=	Exposure duration (yr)
ED_{infant}	=	Exposure duration of infant to breast milk (yr)
EF	=	Exposure frequency (days/yr)
ET	=	Exposure time (hrs/day)
f_1	=	Fraction of ingested dioxin that is stored in fat (unitless)
f_2	=	Fraction of mother's weight that is fat (unitless)
f_3	=	Fraction of mother's breast milk that is fat (unitless)
f_4	=	Fraction of ingested COPC that is absorbed (unitless)
F_{ag}	=	Fraction of produce that is contaminated (unitless)
F_{bg}	=	Fraction of belowground produce that is contaminated (unitless)

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LIST OF VARIABLES

F_{dw}	=	Fraction of drinking water that is contaminated (unitless)
F_{fish}	=	Fraction of fish that is contaminated (unitless)
F_j	=	Fraction of animal tissue *j* that is contaminated (unitless)
F_{soil}	=	Fraction of soil that is contaminated (unitless)
h	=	Half-life of dioxin in adults (days)
$HI_{inh(j)}$	=	Hazard index for target organ effect *j* through direct inhalation of all COPCs (unitless)
HI_j	=	Hazard index for exposure pathway *j* (unitless)
HQ_i	=	Hazard quotient for COPC *I* (unitless)
$HQ_{inh(I)}$	=	Hazard quotient for direct inhalation of COPC *I* (unitless)
I	=	Total daily intake of COPC (mg COPC/kg BW-day)
I_i	=	Daily intake of COPC *I* from animal tissue *j* (mg COPC/kg BW-day)
I_{ag}	=	Daily intake of COPC from produce (mg COPC/kg BW-day)
I_{bg}	=	Daily intake of COPC from belowground produce (mg COPC/kg BW-day
I_{dw}	=	Daily intake of COPC from drinking water (mg COPC/kg BW-day)
I_{fish}	=	Daily intake of COPC from fish (mg COPC/kg BW-day)
I_{soil}	=	Daily intake of COPC from soil (mg COPC/kg BW-day)
Inhalation CSF	=	Inhalation cancer slope factor $(mg/kg\text{-}day)^{-1}$
IR	=	Inhalation rate (m^3/hr)
IR_{milk}	=	Ingestion rate of breast milk by the infant (kg/day)
LADD	=	Lifetime average daily dose (mg COPC/kg BW-day)
m	=	Average maternal intake of dioxin for each adult exposure scenario (mg COPC/kg BW-day)
Oral CSF	=	Oral cancer slope factor $(mg/kg\text{-}day)^{-1}$
Pd	=	Aboveground exposed produce concentration due to direct (wet and dry) deposition onto plant surfaces (mg COPC/kg DW)
P_i	=	Total COPC concentration in plant type *I* eaten by the animal (mg/kg DW)
Pr	=	Aboveground exposed and protected produce concentration due to root uptake (mg COPC/kg DW)
Pr_{bg}	=	Belowground produce concentration due to root uptake (mg COPC/kg DW)
Pv	=	Concentration of COPC in plant due to air-to-plant transfer (mg COPC/kg DW)
RfC	=	Reference concentration (mg/kg)
RfD	=	Reference dose (mg/kg-day)
Total Cancer Risk	=	Individual lifetime cancer risk through indirect exposure to all COPC carcinogens (unitless)

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LIST OF VARIABLES

Total Cancer Risk$_{inh}$	=	Total individual lifetime cancer risk through direct inhalation of all COPC carcinogens (unitless)
URF	=	Unit risk factor $(\mu g/m^3)^{-1}$

TABLE C-1-1

COPC INTAKE FROM SOIL

Description

This equation calculates the daily intake of COPC from soil consumption. The soil concentration will vary with each scenario location, and the soil consumption rate varies for children and adults. Uncertainties associated with this equation include:

(1) The amount of soil intake is assumed to be constant and representative of the exposed population. This assumption may under- or overestimate I_{soil}.
(2) The standard assumptions regarding period exposed may not be representative of any actual exposure situation. This assumption may under- or overestimate I_{soil}.

Equation

$$I_{soil} = \frac{Cs \cdot CR_{soil} \cdot F_{soil}}{BW}$$

Variable	Description	Units	Value
I_{soil}	Daily intake of COPC from soil	mg/kg-day	

TABLE C-1-1

COPC INTAKE FROM SOIL

Variable	Description	Units	Value
Cs	Average soil concentration over exposure duration	mg/kg	**Varies** This variable is COPC- and site-specific, and is calculated using the equation in Table B-1-1. *Cs* will vary based on whether the COPC is carcinogenic or noncarcinogenic. For carcinogenic COPCs, this value is equal to the soil concentration averaged over the exposure duration (Table B-1-1) (U.S. EPA 1994 and NC DEHNR 1997). For noncarcinogenic COPCs, this value is equal to the highest annual soil concentration occurring within the exposure duration. The highest annual soil concentration would occur at the end of the time period of combustion (Table B-1-1) (U.S. EPA 1994 and NC DEHNR 1997). Uncertainties associated with this variable include: (1) The time period over which deposition of COPCs due to hazardous waste combustion is assumed to be conservative, long-term value. This assumption may overestimate *Cs*. (2) Exposure durations are based on historical mobility rates, and may not remain constant. This assumption may overestimate or underestimate *Cs*. (3) Mobility studies indicate that most receptors that move remain in the vicinity of the emission source, however, the likelihood that these short distances moves will influence exposure based on factors such as atmospheric transport of pollutants cannot be predicted accurately. This assumption may overestimate or underestimate *Cs*. (4) The use of a value of 0 for T_1 does not account for exposure that may have occurred prior to hazardous waste combustion. This may underestimate *Cs*. (5) For soluble COPCs, leaching may lead to movement below 1 cm in untilled soils; resulting in a greater mixing depth. This uncertainty may overestimate *Cs*. (6) Deposition to hard surfaces may result in dust residues that have negligible dilution compared to other residues. This uncertainty may underestimate *Cs*.

TABLE C-1-1

COPC INTAKE FROM SOIL

Variable	Description	Units	Value
CR_{soil}	Consumption rate of soil	kg/day	**0.00005 to 0.0001** The soil consumption rate varies for the adult and child receptors (U.S. EPA 1997). <u>Receptor</u> <u>Intake Rate (kg/day)</u> Adult 0.00005 Child 0.0001 U.S. EPA (1997) states that a child intake rate of 0.0002 kg/day for a child receptor may be used as a conservative estimate of exposure. U.S. EPA (1997) references studies done by Hawley (1985) and Calabrese (1990) as the sources used to derive soil consumption rates. Uncertainties associated with this variable include: (1) Tracer studies have resulted in wide ranging estimates of the amount of soil and dust ingested by young children, making it difficult to identify a single value which should be used. Additionally it is extremely difficult to separate the contribution of exposure resulting from exterior soil vs. interior dust. As a result the intake rate is reported as the combined rate for soils and dusts. This uncertainty may under- or overestimate CR_{soil}. (2) The recommended intake rates may not accurately represent behavioral characteristics since they are upper estimates. This uncertainty may overestimate CR_{soil}. (3) The intake rates represent normal mouthing tendencies. Some children exhibit abnormal mouthing behavior or "pica" and would have much higher intake rates. This uncertainty may considerably underestimate CR_{soil}.
F_{soil}	Fraction of soil that is contaminated	unitless	**1.0** U.S. EPA OSW assumes the fraction of consumed soil contaminated is equal to 1.0. This is consistent with NC DEHNR (1997) and U.S. EPA (1994), which assumes the fraction of consumed soil contaminated is 1.0 for all exposure scenarios. Uncertainty associated with this variable include: U.S. EPA guidance recommends the fraction of consumed soil contaminated is equal to 1.0. However, due to variations in the proximity of the receptor to the contaminated source, size of the contaminated source, receptors of concern, mobility of receptors, and nature of exposure, F_{soil} may be overestimated or underestimated.

Variable	Description	Units	Value
BW	Body weight	kg	**15 or 70** U.S. EPA OSW recommends using default values of 70 (adults) and 15 (children). These default values are consistent with U.S. EPA (1991; 1994). Uncertainty associated with this variable include: These body weights represent the average weight of an adult and child. However, depending on the actual receptor, body weights may be higher or lower. These default values may overestimate or underestimate actual body weights. However, the degree of under- or overestimation is not expected to be significant.

TABLE C-1-1

COPC INTAKE FROM SOIL

(Page 5 of 5)

REFERENCES AND DISCUSSION

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

This document is cited by U.S. EPA (1997) as a source of information used to derive soil consumption rates.

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

This document is cited by U.S. EPA (1997) as a source of information used to derive soil consumption rates.

NC DEHNR. 1997. *North Carolina Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units. January.*

This document is one of the sources for the equation in Table C-1-1. This document also states that (1) for carcinogenic COPCs, *Cs* is equal to the soil concentration averaged over the exposure duration; however, no reference document is cited and (2) for noncarcinogenic COPCs, *Cs* is equal to the highest annual soil concentration occurring within the exposure duration; the highest annual soil concentration would occur at the end of the time period of emissions.

U.S. EPA. 1991. *Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors.* Office of Solid Waste and Emergency Response. OSWER Directive 9285.6-03. Washington, D.C. March 21.

This document is cited as the reference source document of the exposure frequency and body weight variables.

U.S. EPA. 1994. *Revised Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document is one of the sources for the equation in Table C-1-1. This document also states that (1) for carcinogenic COPCs, *Cs* is equal to the soil concentration averaged over the exposure duration; however, no reference document is cited and (2) for noncarcinogenic COPCs, *Cs* is equal to the highest annual soil concentration occurring within the exposure duration; the highest annual soil concentration would occur at the end of the time period of emissions.

U.S. EPA. 1997. *Exposure Factors Handbook.* Office of Research and Development. EPA/600/P-95/002F. August.

This document is the source for soil consumption rates.

TABLE C-1-2

COPC INTAKE FROM PRODUCE

Description

This equation calculates the daily intake of COPC from ingestion of exposed aboveground, protected aboveground, and belowground produce. The consumption rate varies for children and adults, and for the type of produce. The concentration in exposed aboveground, protected aboveground, and belowground produce will also vary with each scenario location.

Consumption rates were derived from the *Exposure Factors Handbook* (U.S. EPA 1997). U.S. EPA (1997) presents consumption rates based on body weight; therefore, body weight is not included as a variable in the calculation of I_{ag}.

Uncertainties associated with this equation include the following:

(1) The amount of produce intake is assumed to be constant and representative of the exposed population. This assumption may under- or overestimate I_{ag}.
(2) The standard assumptions regarding period exposed may not be representative of any actual exposure situation. This assumption may under- or overestimate I_{ag}.

Equation

$$I_{ag} = [((Pd + Pv + Pr) \cdot CR_{ag}) + (Pr \cdot CR_{pp}) + (Pr_{bg} \cdot CR_{bg})] \cdot F_{ag}$$

Variable	Description	Units	Value
I_{ag}	Daily intake of COPC from produce	mg/kg-day DW	
Pd	Aboveground exposed produce concentration due to direct (wet and dry) deposition onto plant surfaces	mg/kg	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-2-7. Uncertainties associated with this variable include the following: (1) The calculation of *kp* values does not consider chemical degradation processes. Inclusion of chemical degradation processes would decrease the amount of time that a chemical remains on plant surfaces (half-time) and thereby may increase *kp* values. *Pd* decreases with increased *kp* values. Reduction of half-time from the assumed 14 days to 2.8 days, for example, would decrease *Pd* about five-fold. (2) The calculation of other parameter values (for example, *Fw* and *Rp*) is based directly or indirectly on studies of vegetation other than aboveground produce (primarily grasses). Uncertainty is introduced to the extent that the calculated parameter values do not accurately represent aboveground produce-specific values.

TABLE C-1-2

COPC INTAKE FROM PRODUCE

Variable	Description	Units	Value
Pv	Aboveground exposed produce concentration due to air-to-plant transfer	mg/kg	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-2-8. Uncertainties associated with this variable include the following: (1) The range of values for the variable *Bv* (air-to-plant biotransfer factor) is about 19 orders of magnitude for organic COPCs. (2) The algorithm used to calculate values for the variable F_v assumes a default value for the parameter S_T (Whitby's average surface area of particulates [aerosols]) of background plus local sources rather than an S_T value for urban sources. If a specific site is located in an urban area, the use of the latter S_T value may be more appropriate. The S_T value for urban sources is about one order of magnitude greater than that for background plus local sources and would result in a lower F_v value; however, the F_v value is likely to be only a few percent lower.
Pr	Aboveground exposed and protected produce concentration due to root uptake	mg/kg	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-2-9. Uncertainty associated with this variable include the following: Estimated COPC-specific soil-to-plant bioconcentration factors (*Br*) may not be representative of site-specific conditions.
Pr_{bg}	Belowground produce concentration due to root uptake	mg/kg	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-2-10. Uncertainty associated with this variable include the following: Estimated COPC-specific soil-to-plant bioconcentration factors (*Br*) may not be representative of site-specific conditions.

Variable	Description	Units	Value
CR_{ag}; CR_{pp}; CR_{bg}	Consumption rate of aboveground, protected aboveground, and belowground produce, respectively	kg/kg-day DW	This variable is site-specific. The recommended default values represent the total of the following produce-specific ingestion rates: Plant Type — Receptor — Ingestion Rate (kg/kg-day DW) Exposed Aboveground Produce (Cr_{ag}) — Adult — 0.0003 Exposed Aboveground Produce (Cr_{ag}) — Child — 0.00042 Protected Aboveground Produce (Cr_{pp}) — Adult — 0.00057 Protected Aboveground Produce (Cr_{pp}) — Child — 0.00077 Belowground Produce (Cr_{bg}) — Adult — 0.00014 Belowground Produce (Cr_{bg}) — Child — 0.00022 Ingestion rates were derived from U.S. EPA (1997), Tables 13-61 and 13-65. The ingestion rates listed in U.S. EPA (1997) are derived from the 1987-1988 USDA National Food Consumption Survey and may be used to assess exposure to contaminants in foods grown, raised, or caught at a specific site. The ingestion rates were adjusted for cooking and preparation loss as recommended by U.S. EPA (1997). The average preparation and cooking loss used for exposed vegetables was 15.8 percent (U.S. EPA 1997). However, it is assumed that no preparation and cooking loss occurs with exposed fruits because it is further assumed the fruit is eaten in the raw form. In addition, ingestion rates for the child receptor represent a time-weighted mean from the respective tables. Uncertainty associated with this variable include the following: The recommended ingestion rates are based on national average home produced consumption rates. Site-specific ingestion rates may be higher or lower than those recommended. Therefore, use of the recommended ingestion rates may under- or overestimate I_{ag}.

TABLE C-1-2

COPC INTAKE FROM PRODUCE

Variable	Description	Units	Value
F_{ag}	**Fraction of produce that is contaminated**	unitless	**Varies** This variable is site-specific. U.S. EPA OSW recommends the following default values in the absence of site-specific information, consistent with U.S. EPA (1994). The fraction of produce that is contaminated varies for each exposure scenario: Exposure Scenario — F_{ag} Adult Resident — 0.25 Child Resident — 0.25 Subsistence Farmer — 1.0 Subsistence Farmer Child — 1.0 Subsistence Fisher — 0.25 Subsistence Fisher Child — 0.25 U.S. EPA (1994) cites U.S. EPA (1990) as the reference source for the F_{ag} value for the adult resident, child resident, subsistence fisher, and subsistence fisher child. U.S. EPA (1994) does not provide a reference for the F_{ag} value for the subsistence farmer and the subsistence farmer child. The following uncertainty is associated with this variable: Fraction of produce that is contaminated will vary from site to site. Use of default values may overestimate or underestimate F_{ag}.

REFERENCES AND DISCUSSION

Baes, C.F., R.D. Sharp, A.L. Sjoreen, and R.W. Shor. 1984. *Review and Analysis of Parameters and Assessing Transport of Environmentally Released Radionuclides through Agriculture.* Oak Ridge National Laboratory. Oak Ridge, Tennessee.

This document is cited as a source for *Br* values.

U.S. EPA 1990. *Exposure Factors Handbook.* Office of Health and Environmental Assessment, Exposure Assessment Group. Washington, D.C. March.

This is the document cited as the source of the fraction of produce that is contaminated (F_{ag}) the adult resident, child resident, and subsistence fisher. U.S. EPA assumes that F_{ag} for the subsistence fisher child is the same as for the subsistence fisher.

U.S. EPA 1992. *Technical Support Document for Land Application of Sewage Sludge.* Volumes I and II. Office of Water. Washington, D.C. EPA 822/R-93-001a.

This document is cited as a soource for plant uptake response slope factors.

U.S. EPA. 1994. *Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Waste.* Office of Emergency and Remedial Response. Office of Solid Waste.

This document is cited as the source of the fraction of produce that is contaminated (F_{ag}) for the subsistence farmer (U.S. EPA assumes that F_{ag} for the subsistence farmer child is the same as for the subsistence farmer).

U.S. EPA. 1997. *Exposure Factors Handbook.* Office of Research and Development. EPA/600/P-95/002F. August.

This document is the source for produce consumption rates.

TABLE C-1-3

COPC INTAKE FROM BEEF, MILK, PORK, POULTRY, AND EGGS

Description

This equation calculates the daily intake of COPCs from the ingestion of animal tissue (where the *i* in the equation refers to beef, milk, pork, poultry, or eggs). The consumption rate varies for children and adults and for the type of animal tissue (*j*). The concentration in the animal tissue will also vary with each scenario location.

Consumption rates were derived from the *Exposure Factors Handbook* (U.S. EPA 1997). U.S. EPA (1997) presents consumption rates based on body weight; therefore, body weight is not included as a variable in the calculation of I_i.

Uncertainties associated with this equation include the following:

(1) The amount of animal tissue intake is assumed to be constant and representative of the exposed population. This assumption may under- or overestimate I_i.
(2) The standard assumptions regarding period exposed may not be representative of any actual exposure situation. This assumption may under- or overestimate I_i.

Equation

$$I_i = A_i \cdot CR_i \cdot F_i$$

Variable	Description	Units	Value
I_i	Daily intake of COPC *i* from animal *j* tissue	mg/kg-day	

TABLE C-1-3

COPC INTAKE FROM BEEF, MILK, PORK, POULTRY, AND EGGS

Variable	Description	Units	Value
A_j	Concentration of COPC *i* in animal tissue *j*	mg/kg FW	**Varies** This variable is COPC- and site-specific, and is calculated by using the equations in Tables B-3-10, B-3-11, B-3-12, B-3-13, and B-3-14. Uncertainties associated with this variable include the following: (1) Based on the information provided, A_{beef} and A_{pork} are dependent on the concentrations of COPCs estimated in plant feeds and soil, and the biotransfer factors estimated for each constituent. To the extent the estimated concentrations in plants and the biotransfer factors do not reflect site-specific on local conditions, A_{beef} may be under- or overestimated. (2) Uptake of COPCs into chicken and eggs has typically been applied only to PCDDs and PCDFs but could possibly be used to calculate A_{chick} and A_{egg} resulting from other COPCs. (3) The assumption that 10 percent of a chicken's diet is soil may not represent site-specific or local conditions of chickens raised on subsistence farms. Stephens, Petreas, and Hayward (1992) and Stephens, Petreas, and Hayward (1995) suggest the percentage of soil in the diet of chickens raised under field conditions may be greater than 10 percent. Therefore, the concentration of COPCs in eggs, A_{egg}, and the concentration of COPCs in chicken, A_{chick}, may be underestimated.

Variable	Description	Units	Value
CR_j	Consumption rate of animal tissue *j*	kg/kg-day FW	**Varies** This variable is site-specific. U.S. EPA OSW recommends the ingestion rates of animal tissues (see the equation in Table C-1-4 for fish ingestion). The recommended ingestion rates for homegrown beef, milk, poultry, eggs, and pork have been derived from U.S. EPA (1997): Animal Tissue Ingestion Rates (kg/kg-day FW) Adult / Child Homegrown Beef: 0.00114 / 0.00051 Homegrown Milk: 0.00842 / 0.01857 Homegrown Poultry: 0.00061 / 0.000425 Homegrown Eggs: 0.00062 / 0.000438 Homegrown Pork: 0.00053 / 0.000398 Ingestion rates were determined from U.S. EPA (1997) Tables 13-28, 13-36, 13-43, 43-54, and 13-55. The ingestion rates listed in U.S. EPA (1997) were derived from the 1987-1988 USDA National Food Consumption Survey and may be used to assess exposure to contaminants in foods grown, raised, or caught at a specific site. Prior to the adjustment for cooking and preparation loss, the mean individual meat consumption rates were weighted by age group. The ingestion rates were then adjusted for cooking and preparation loss as recommended in U.S. EPA (1997). The total preparation and cooking loss was in the range of 45 to 54 percent for beef, pork, and poultry. In addition, ingestion rates for the child receptor represent a time-weighted mean from the respective tables. Where data for a specific age group was incomplete, the intake was extrapolated using data from the general population (Tables 11-11 and 11-13 of U.S. EPA 1997). Specifically, an age-group home produced item intake was derived by multiplying the total mean intake for that home produced item by the ratio of the item- and age-group general population intake rate (Tables 11-11 and 11-13 of U.S. EPA 1997) to a total individual general population intake rate for that item (Tables 11-11 and 11-13 of U.S. EPA 1997). For example: Child (01-02) home produced beef intake rate = 2.45 g/kg-day (Table 13-36) x $\frac{10 \text{ g/day (Table 11-11)}}{32 \text{ g/day (Table 11-11)}}$ U.S. EPA (1997) provides information for total home produced dairy (Table 13-28 of U.S. EPA 1997), but does not specify intake for fluid milk.

TABLE C-1-3

COPC INTAKE FROM BEEF, MILK, PORK, POULTRY, AND EGGS

Variable	Description	Units	Value
CR_j *continued*	Consumption rate of animal tissue *j*	kg/kg-day FW	For the metals mercury, selenium, and cadmium, the concentration in beef, milk, and pork, and the consumption rate are in kilograms dry weight per day. Wet-weight to dry-weight conversion information for beef, milk, and pork is presented in U.S. EPA (1997) The following uncertainty is associated with this variable: The recommended tissue-specific consumption rates may not accurately reflect site-specific in local conditions. As a result, tissue-specific intakes may be over- or underestimated.
F_j	Fraction of animal tissue *j* that is contaminated	unitless	**1.0** This variable is site-specific. U.S. EPA OSW recommends an F_j of 1.0 for all animal tissues consumed. This recommendation is consistent with NC DEHNR (1997). The following uncertainty is associated with this variable: The fraction of animal tissue that is contaminated is site-specific; therefore, any of the following may be under- or overestimated: variations in the proximity of the receptor to the contaminated source, size of the contaminated source, receptors of concern, mobility of receptors, and nature of exposure.

REFERENCE AND DISCUSSIONS

Stephens, R.D., M.X. Petreas, and D.G. Hayward. 1992. "Biotransfer and Bioaccumulation of Dioxins and Dibenzofurans from Soil." Hazardous Materials Laboratory, California Department of Health Services. Berkeley, California. Presented at the 12th International Symposium on Dioxins and Related Compounds. August 24 through 28. University of Tampere, Tampere, Finland.

This document is cited as the source of the assumption that free-range chickens ingest soil as 10 percent of their diet and as the source of the dioxin and furan congeners-specific *BCF*s recommended by NC DEHNR (1997). However this document does not clearly reference or document the assumption that soil represents 10 percent of a free-range chicken's diet. The document appears to cite two other documents as supporting its assumption: (1) Chang, Hayward, Goldman, Harnly, Flattery and Stephens (1989) and (2) Petreas, Goldman, Hayward, Chang, Flattery, Wiesmuller, Stephens, Fry, and Rappe (1992).

Also, this document presents dioxin and furan congener-specific *BCF*s (thigh) for the low- exposure group after 80 days of a 178-day total exposure period. The chickens in the low-dose group were fed a diet containing 10 percent soil with a PCDD/PCDF concentration of 42 ppt I-TEQ. Chickens in the high-dose group were fed a diet containing 10 percent soil with a PCDD/PCDF concentration of 458 ppt I-TEQ; *BCF* results were not presented from the high-dose group.

Stephens, R.D., M.X. Petreas, and D.G. Hayward. 1995. "Biotransfer and Bioaccumulaton of Dioxins and Furans from Soil: Chickens as a Model for Foraging Animals." *The Science of the Total Environment.* Volume 175: 253-273.

This document is an expansion of the results originally presented in Stephens, Petreas, and Hayward (1992). In particular, this document suggests that the percentage of soil in the diet of chickens raised under field conditions is likely to be greater than 10 percent, the value that was used in the experimental study presented in this document.

Also, this document presents dioxin and furan congener-specific *BCF*s (thigh) under two exposure schemes; low exposure and high exposure. The white leghorn (Babcock D 300) chickens in the low group were fed a diet containing 10 percent soil with a PCDD/PCDF concentrations of 42 ppt I-TEQ. Chickens in the high group were fed a diet containing 10 percent soil with a PCDD/PCDF concentration of 460 ppt I-TEQ (some congeners were fortified by spiking).

The *BCF*s presented for low- and high-dose groups both represent averages of results from Day-80 and Day-164 of a total 178-day exposure period.

U.S. EPA. 1997. *Exposure Factors Handbook.* Office of Research and Development. EPA/600/P-95/002F. August.

This document is the source for home produced beef, milk, pork, poultry, and egg consumption rates.

TABLE C-1-4

COPC INTAKE FROM FISH

(Page 1 of 4)

Description

This equation calculates the daily intake of COPCs from the ingestion of fish. Consumption rates were derived from the *Exposure Factors Handbook* (U.S. EPA 1997). U.S. EPA (1997) presents consumption rates based on body weight; therefore, body weight is not included as a variable in the calculation of I_{fish}.

The limitations and uncertainty introduced in calculating this value include the following:

(1) The amount of fish intake is assumed to be constant and representative of the exposed population. This assumption may under- or overestimate I_{fish}.
(2) The standard assumptions regarding period exposed may not be representative of any actual exposure situation. This assumption may under- or overestimate I_{fish}.

Equation

$$I_{fish} = C_{fish} \cdot CR_{fish} \cdot F_{fish}$$

Variable	Description	Units	Value
I_{fish}	Daily intake of COPC from fish	mg/kg-day	
C_{fish}	Concentration in fish	mg/kg	**Varies** This variable is COPC- and site-specific, and is calculated by using the equations in Tables B-4-26 through B-4-28; the fish concentration will vary for each water body. The following uncertainty is associated with this variable: The methodology does not account for concentration variations across fish species. Different species may accumulate COPCs to different extents depending, for example, on their feeding habits and fat content. This may cause C_{fish} to be under- or overestimated.

TABLE C-1-4

COPC INTAKE FROM FISH

Variable	Description	Units	Value
CR_{fish}	Consumption rate of fish	kg/kg-day FW	**Varies** The consumption rate varies for the receptor considered. The following home produced or caught ingestion rates for fish were derived from U.S. EPA (1997): <u>Receptor</u> — <u>Ingestion Rate (kg/kg-day FW)</u> Adult — 0.00117 Child — 0.000759 Ingestion rates were determined from U.S. EPA (1997) Table 13-23. The ingestion rates listed in U.S. EPA (1997) were derived from the 1987-1988 USDA National Food Consumption Survey and may be used to assess exposure to contaminants in foods grown, raised, or caught at a specific site. Prior to the adjustment for cooking and preparation loss, the mean individual fish consumption rates were weighted by age group. The ingestion rates were then adjusted for cooking and preparation loss as recommended in U.S. EPA (1997). The total preparation and cooking loss for fish was 38 percent. In addition, ingestion rates for the child receptor represent a time-weighted mean from the respective tables. Where data for a specific age group was incomplete, the intake was extrapolated using data from the general population (Table 10-46 of U.S. EPA 1997). Specifically, an age-group home produced item intake was derived by multiplying the total mean intake for that home produced item by the ration of the item- and age-group general population intake rate (Table 10-46 of U.S. EPA 1997) to a total individual general population intake rate for that item (Tables 10-46 of U.S. EPA 1997). For example: $\text{Child (01-02) home produced fish intake rate} = [2.07 \text{ g/kg-day (Table 13-23)}] \times \frac{67 \text{ g/day (Table 10-46)}}{117 \text{ g/day (Table 10-46)}}$ This value was then included in the determination of a time weighted average and subsequently adjusted for cooking and preparation loss. Uncertainties introduced by assumptions made to calculate this value include the following: (1) The intake rates presented do not take into account the types of fish that will be present in the water body. Separate intake rates are needed for freshwater and estuarine fish and shellfish, depending on the nature of the local surface water body. This assumption can overestimate or underestimate CR_{fish}.

Variable	Description	Units	Value
CR_{fish} *continued*	Consumption rate of fish	kg/kg-day FW	(2) These intake rates do not represent long behavior patterns, which is the focus of the exposure assessments used to support chronic health effects. This introduces uncertainty into the estimates of medians and other percentiles. This assumption can overestimate or underestimate CR_{fish}. (3) The intake rates represent total intake rates of home-caught fish. Where use of site-specific information would reveal the amount of fish consumed from waters within the study area, this information should be used. This assumption can overestimate or underestimate CR_{fish}.
F_{fish}	Fraction of fish that is contaminated	unitless	**1.0** U.S. EPA OSW recommends that this default value be used if site-specific information is not available. The contaminated fraction will vary with each exposure scenario; however, NC DEHNR (1997) and U.S. EPA (1994) assume that this value equals 1.0 for the subsistence fisher. The following uncertainty is associated with this variable: Using 1.0 as a default value for fraction of fish that is contaminated assumes that receptors consume only contaminated fish; this assumption may overestimate F_{fish}.

REFERENCES AND DISCUSSION

NC DEHNR. 1997. *NC DEHNR Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Combustion Units.* January.

This document is one of the reference source documents for the equation in Table C-1-4.

U.S. EPA. 1994. *Revised Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document is one of the reference source documents for the equation in Table C-1-4.

U.S. EPA. 1997. *Exposure Factors Handbook.* Office of Research and Development. EPA/600/P-95/002F. August.

This document is the source for home-caught fish consumption rates.

TABLE C-1-5

COPC INTAKE FROM DRINKING WATER

Description

This equation calculates the daily intake of COPC from drinking water. COPC intake from drinking water is calculated from the concentration of COPC dissolved in the water column of each surface water body or watershed identified as a drinking water source. The dissolved concentration is used for calculating COPC intake from drinking water because it is assumed the water is filtered prior to human consumption. The COPC concentration will vary for each water body. The consumption rate varies for children and adults.

Uncertainties associated with this equation include the following:

(1) The amount of drinking water intake is assumed to be constant and representative of the exposed population. This assumption may under- or overestimate I_{dw}.
(2) The standard assumptions regarding period exposed may not be representative of any actual exposure situation. This assumption may under- or overestimate I_{dw}.

Equation

$$I_{dw} = \frac{C_{dw} \cdot CR_{dw} \cdot F_{dw}}{BW}$$

Variable	Description	Units	Value
I_{dw}	Daily intake of COPC from drinking water	mg/kg-day	
C_{dw}	Dissolved phase water concentration	mg/L	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-4-24. Uncertainties associated with this variable include the following: All of the variables in the equation in Table B-4-24 are COPC- and site-specific. Therefore, the use of default values rather than site-specific values, for any or all of these variables, will contribute to the under- or overestimation of C_{wt}. The degree of uncertainty associated with the variables d_w and d_b is expected to be minimal because information for estimating a variable (d_w) is generally available and the probable range for a variable (d_b) is narrow. The uncertainty associated with the variables F_{water} and C_{wtot} is associated with estimates of *OC* content. Because OC content values can vary widely for different locations in the same medium, using default OC values may result in significant uncertainty in specific cases.

TABLE C-1-5

COPC INTAKE FROM DRINKING WATER

Variable	Description	Units	Value
CR_{dw}	Rate of consumption of drinking water	L/day	**0.67 or 1.4** This variable is site-specific. U.S. EPA OSW recommends default values of 1.4 (adult) and 0.67 (child) in the absence of site-specific data. The recommendation for the average adult consumption rate of drinking water is based on information cited in U.S. EPA (1997). For the child receptor, U.S. EPA (1997) provides recommended drinking water intake rates for various age groups in Table 3-30. The child default drinking water intake was derived by using a time-weighted average for the age groups 0 to 6 years of age. The following uncertainty is associated with this variable: The average consumption rate of drinking water is based on the average intake observed from five studies. The number of studies conduct may underestimate or underestimate CR_{dw}.
F_{dw}	Fraction of drinking water that is contaminated	unitless	**1.0** This variable is site-specific. U.S. EPA OSW, consistent with U.S. EPA (1994), recommends assuming 1.0 for the fraction of drinking water that is contaminated. The following uncertainty is associated with this variable: Some receptors may consume a fraction of their drinking water from sources unimpacted by facility emissions. Therefore, this assumption will likely overestimate F_{dw}.
BW	Body weight	kg	**15 or 70** This variable is site-specific. U.S. EPA OSW recommends using default values of 70 (adults) and 15 (children) in the absence of site-specific information. These default values are consistent with U.S. EPA (1991; 1994). Uncertainties associated with this variable include: These body weights represent the avearge weight of an adult and child. However, depending on the receptor, the body weights may be higher or lower. These default values may overestimate or underestimate actual body weights. However, the degree of under- or overestimation is not expected to be significant.

TABLE C-1-5

COPC INTAKE FROM DRINKING WATER

(Page 3 of 3)

REFERENCES AND DISCUSSION

U.S. EPA. 1991. *Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors.* Office of Solid Waste and Emergency Response. OSWER Directive 9285.6-03. Washington, D.C. March 21.

This document is cited as the reference source document of the exposure frequency and body weight variables.

U.S. EPA. 1994. *Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes.* Office of Emergency and Remedial Response. Office of Solid Waste.

This document was cited as the source of the fraction of drinking water that is contaminated.

U.S. EPA. 1997. *Exposure Factors Handbook.* Office of Research and Development. EPA/600/P-95/002F. August.

This document is the source for the drinking water consumption rates.

TABLE C-1-6

TOTAL DAILY INTAKE

Description

This equation calculates the daily intake of COPC via all indirect exposure pathways. As discussed in Chapter 4 and Table 4-1, the indirect exposure pathways considered in the calculation of the total daily intake of COPCs are specific to the recommended exposure scenario evaluated and the representative exposure setting. Daily intake values from exposures scenarios which are not evaluated in a respective exposure scenario may be assumed to be zero when calculating the total daily intake of COPC (I).

Uncertainties associated with this equation include the following:

(1) The uncertainties associated with estimates of total intake are those associated with each of the medium- or tissue-specific intakes.
(2) To the extent that medium- or tissue-specific intakes do not accurately represent site-specific local conditions local conditions, I may be under- or overestimated.

Equation

$$I = I_{soil} + I_{ag} + I_{beef} + I_{milk} + I_{fish} + I_{pork} + I_{poultry} + I_{eggs} + I_{dw}$$

Variable	Description	Units	Value
I	Total daily intake of COPC	mg/kg-day	
I_{soil}	Daily intake of COPC from soil	mg/kg-day	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table C-1-1. The value for this variable will vary for each receptor and each exposure scenario location. Uncertainties associated with this variable include the following: (1) The amount of soil intake is assumed to be constant and representative of the exposed population. This assumption may under- or overestimate I_{soil}. (2) The standard assumptions regarding period exposed may not be representative of any actual exposure situation. This assumption may under- or overestimate I_{soil}.

TABLE C-1-6

TOTAL DAILY INTAKE

Variable	Description	Units	Value
I_{ag}	Daily intake of COPC from aboveground produce	mg/kg-day DW	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table C-1-2. The value for this variable will vary for each receptor and each exposure scenario location. Uncertainties associated with this variable include the following: (1) The amount of produce intake is assumed to be constant and representative of the exposed population. This assumption may under- or overestimate I_{ag}. (2) The standard assumptions regarding period exposed may not be representative of any actual exposure situation. This assumption may under- or overestimate I_{ag}.
I_{beef}; I_{milk}; I_{pork}; $I_{poultry}$; I_{eggs}	Daily intake of COPC from beef, milk, pork, poultry, and eggs	mg/kg-day FW	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table C-1-3. The value for this variable will vary for each receptor and each exposure scenario location. Uncertainties associated with this variable include the following: (1) The amount of animal tissue intake is assumed to be constant and representative of the exposed population. This assumption may under- or overestimate I_{beef}, I_{milk}, I_{pork}, $I_{poultry}$, and I_{eggs}. (2) The standard assumptions regarding period exposed may not be representative of any actual exposure situation. This assumption may under- or overestimate I_{beef}, I_{milk}, I_{pork}, $I_{poultry}$, and I_{eggs}.
I_{fish}	Daily intake of COPC from fish	mg/kg-day FW	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table C-1-4. The value for this variable will vary for each water body evaluated. Uncertainties associated with this variable include the following: (1) The amount of fish intake is assumed to be constant and representative of the exposed population. This assumption may under- or overestimate I_{fish}. (2) The standard assumptions regarding period exposed may not be representative of any actual exposure situation. This assumption may under- or overestimate I_{fish}.

TABLE C-1-6

TOTAL DAILY INTAKE

(Page 3 of 3)

Variable	Description	Units	Value
I_{dw}	Daily intake of COPC from drinking water	mg/kg-day	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table C-1-5. The value for this variable will vary for each water body evaluated. Uncertainties associated with this variable include the following: (1) The amount of drinking water intake is assumed to be constant and representative of the exposed population. This assumption may under- or overestimate I_{dw}. (2) The standard assumptions regarding period exposed may not be representative of any actual exposure situation. This assumption may under- or overestimate I_{dw}.

TABLE C-1-7

INDIVIDUAL CANCER RISK: CARCINOGENS

Description

This equation calculates the individual cancer risk from indirect exposure to carcinogenic COPCs. The exposure duration varies for different scenarios. Uncertainties associated with this equation include the following:

(1) Default factors for exposure frequency and exposure duration are assumed to represent the highest exposure that is reasonably expected to occur at a site and, in practice, is estimated by combining upper-bound (90th to 95th percentile) values for these exposure parameters, but not all parameters. This assumption may over- or underestimate the $Cancer\ Risk_i$.

(2) Slope factors are used to estimate an upper-bound lifetime probability of an individual developing cancer as a result of exposure to a particular level of a potential carcinogen, and are accompanied by the weight of evidence classification to indicate the strength of the evidence that the agent is a human carcinogen. This classification has the potential to over- or underestimate $Cancer\ Risk_i$.

(3) Risk at low exposure levels is difficult to measure directly either by animal experiments or by epidemiological studies. The development of a cancer slope factor generally entails applying a model to the available data set and using the model to extrapolate from the relatively high doses administered to experimental animals (or the exposures noted in epidemiological studies) to lower exposure levels expected for human contact in the environment. This approach may under- or overestimate *Oral CSF*.

Equation

$$Cancer\ Risk_i = \frac{I \cdot ED \cdot EF \cdot CSF}{AT \cdot 365}$$

Variable	Description	Units	Value
$Cancer\ Risk_i$	Individual lifetime cancer risk through indirect exposure to COPC carcinogen *i*	unitless	
I_i	Daily intake of COPC *i* from animal tissue *j*	mg COPC/kg-BW-day	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table C-1-6. The value for this variable will vary for each exposure pathway and each exposure scenario location. The following uncertainty is associated with this variable: This variable is COPC- and site-specific. See the equation in Table C-1-6 regarding the calculation of and uncertainities associated with this variable.

TABLE C-1-7

INDIVIDUAL CANCER RISK: CARCINOGENS

Variable	Description	Units	Value
ED	Exposure duration	yr	**6, 30, or 40** This variable is exposure scenario-specific: <u>Exposure Scenario</u> — <u>ED</u> Subsistence Farmer — 40 (U.S. EPA 1994) Subsistence Farmer Child — 6 (U.S. EPA 1989) Subsistence Fisher — 30 (U.S. EPA 1994) Subsistence Fisher Child — 6 (U.S. EPA 1989) Adult Resident — 30 (U.S. EPA 1989) Child Resident — 6 (U.S. EPA 1989) The following uncertainty is associated with this variable: This exposure duration is a single value that represents the highest exposure that is reasonably expected to occur at a site. This assumption may overestimate *ED*.
EF	Exposure frequency	days/yr	**350** This variable is site-specific. U.S. EPA OSW recommends the use of this default value in the absence of site-specific information, consistent with U.S. EPA (1991). The following uncertainty is associated with this variable: This exposure frequency is a single value that represents the most frequent exposure that is reasonably expected to occur at a site, assuming 2 weeks of vacation or travel. This assumption may overestimate *EF*.
AT	Averaging time	yr	**70** This variable is site-specific. U.S. EPA OSW recommends the use of this default value in the absence of site-specific information, consistent with U.S. EPA (1989). The following uncertainty is associated with this variable: The recommendation for averaging time may not accurately represent site-specific time; specifically, this single value may under- or overestimate the length of time of exposure.
365	Units conversion factor	day/yr	

TABLE C-1-7

INDIVIDUAL CANCER RISK: CARCINOGENS

Variable	Description	Units	Value
Oral CSF	Oral Cancer Slope Factor	$(mg/kg\text{-}day)^{-1}$	**Varies** This variable is COPC-specific, and should be determined from the COPC tables in Appendix A-3. Uncertainties associated with this variable include the following: (1) Slope factors are used to estimate an upper-bound lifetime probability of an individual developing cancer as a result of exposure to a particular level of a potential carcinogen; and are accompanied by the weight of evidence classification to indicate the strength of the evidence that the agent is a human carcinogen. (2) Risk at low exposure levels is difficult to measure directly either by animal experiments or by epidemiological studies. The development of a cancer slope factor generally entails applying a model to the available data set and using the model to extrapolate from the relatively high doses administered to experimental animals (or the exposures noted in epidemiological studies) to the lower exposure levels expected for human contact in the environment. This approach may under- or overestimate *Oral CSF*.

TABLE C-1-7

INDIVIDUAL CANCER RISK: CARCINOGENS

(Page 4 of 4)

REFERENCES AND DISCUSSION

U.S. EPA. 1989. *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A).* Interim Final. Office of Emergency and Remedial Response. EPA/540/1-89/002. December.

This document is cited as the reference source document of the exposure duration for adult and child residents. This document is also cited as the reference source document for the averaging time for carcinogens.

U.S. EPA. 1991. *Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors.* Office of Solid Waste and Emergency Response. OSWER Directive 9285.6-03. Washington, D.C.

This document is cited as the reference source document of the exposure frequency.

U.S. EPA. 1994. *Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* April 15.

This document is cited as the reference source document of the exposure duration for the subsistence fisher and subsistence farmer.

TABLE C-1-8

HAZARD QUOTIENT: NONCARCINOGENS

Description

This equation calculates the hazard quotient for indirect exposure to noncarcinogenic COPCs. The following uncertainty is associated with this equation.

A chronic *RfD* is an estimate of a daily exposure level for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime. Chronic *RfDs* are specifically developed to be protective for long-term exposure (from 7 years to a lifetime) to a compound. COPC-specific reference doses (*RfD*) are unlikely to underestimate a chemical potential for causing adverse effects.

Equation

$$HQ = \frac{I \cdot ED \cdot EF}{RfD \cdot AT \cdot 365}$$

Variable	Description	Units	Value
HQ	Hazard quotient	unitless	
I_i	Daily intake of COPC *i* from animal tissue *j*	mg COPC/ kg-day	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table C-1-6. The value for this variable will vary for each exposure pathway and each exposure scenario location. Uncertainties associated with this variable are site-specific.
ED	Exposure duration	yr	**6, 30, or 40** Consistent with U.S. EPA (1994b) and NC DEHNR (1997), U.S. EPA OSW recommends the use of the following default values. <u>Exposure Scenario</u> — <u>*ED*</u> Subsistence Farmer — 40 (U.S. EPA 1994a) Subsistence Farmer Child — 6 (U.S. EPA 1989) Subsistence Fisher — 30 (U.S. EPA 1994a) Subsistence Fisher Child — 6 (U.S. EPA 1989) Adult Resident — 30 (U.S. EPA 1989) Child Resident — 6 (U.S. EPA 1989) Uncertainty associated with this variable includes: These exposure durations are single values that represent the highest exposure that is reasonably expected to occur at a site. These values may overestimate *ED* for some individuals.

TABLE C-1-8

HAZARD QUOTIENT: NONCARCINOGENS

Variable	Description	Units	Value
EF	Exposure frequency	days/yr	**350** This variable is site-specific. U.S. EPA OSW recommends the use of this default value in the absence of site-specific data. This value is based on U.S. EPA (1991) and is consistent with U.S. EPA (1994b). Uncertainty associated with this variable includes: This exposure frequency is a single value that represents the most frequent exposure that is reasonably expected to occur at a site with two weeks of vacation or travel. This recommended value may overestimate *EF* for individuals who are away from their home for more than two weeks each year. On the other had, some individuals such as subsistence farmers, may remain at their home (or farm) for more than 350 days per year. In either case, the degree of over- or underestimation is not expected to be significant in most cases.
RfD	Reference Dose	mg/kg-day	**Varies** This variable is COPC-specific, and should be determined from the COPC tables in Appendix A-3. The following uncertainty is associated with this variable: A chronic *RfD* is an estimate of a daily exposure level for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime. Chronic *RfDs* are specifically developed to be protective for long-term exposure (from 7 years to a lifetime) to a compound. COPC-specific *RfDs* are unlikely to underestimate a COPC's potential for causing adverse health effects.
365	Units conversion factor	day/yr	
AT	Averaging time	yr	**6, 30, or 40** This variable is site-specific and related to *ED*. Specifically, the *AT* for noncarcinogens is numerically the same as ED. This default value is consistent with U.S. EPA (1989), U.S. EPA (1991), and U.S. EPA (1994a). Uncertainty associated with this variable includes: The recommendation for averaging time may not accurately represent site-specific time; specifically this single value may under- or overestimate the length of an average adult lifetime.

TABLE C-1-8

HAZARD QUOTIENT: NONCARCINOGENS

REFERENCES AND DISCUSSION

NC DEHNR (1997). *Draft North Carolina Protocol for Performing Indirect Exposure Risk Assessments for Hazardous Waste Exposure Risk Assessments for Hazardous Waste Combustion Units*. January.

U.S. EPA. 1989. *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A)*. Interim Final. Office of Emergency and Remedial Response. EPA/540/1-89/002. December.

This document is cited as the reference source document of the exposure duration for adult and child residents. U.S. EPA OSW assumes that the recommended exposure duration for the child resident may also reasonably be applied to the subsistence farmer child and to the subsistence fisher child.

U.S. EPA. 1991. *Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors*. Office of Solid Waste and Emergency Response. OSWER Directive 9285.6-03. Washington, D.C.

This document is cited as a source document for exposure frequency and averaging time.

U.S. EPA. 1994a. *Estimating Exposure to Dioxin-like Components - Volume III: Site-Specific Assessment Procedure*. Review Draft. Office of Research and Development. Washington D.C. EPA/600/6-88/005Cc. June.

This document is cited by U.S. EPA (1994b) as the same document for the recommended default exposure duration (*ED*) values for the subsistence farmer and subsistence fisher. The *ED* value of 40 years recommended for both the subsistence farmer and the subsistence fisher is based on the assumption that "farmers live in one location longer than the general population".

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities*. Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document recommends the following:

- An exposure frequency of 350 days per year
- Recepter-specific exposure duration values as presented in U.S. EPA (1994a)—subsistence fisher (40 years) and subsistence farmer (40 years) and U.S. EPA (1989)—adult resident (30 years) and child resident (6 years)
- Adult and child body weights of 70 kg and 15 kg, respectively

TABLE C-1-9

TOTAL CANCER RISK: CARCINOGENS

Description

For carcinogens, cancer risks are added across all carcinogenic COPCs. See Appendix A for identification of carcinogens. Uncertainty associated with this equation includes the following:

Total Cancer Risk assumes that different carcinogens affect the same target organ to produce a cancer response, ignoring potential antagonistic or synergistic effects or disparate effects on different target organs.

Equation

$$Total\ Cancer\ Risk = \sum_i Cancer\ Risk_i$$

Variable	Description	Units	Value
Total Cancer Risk	Individual lifetime cancer risk through indirect exposure to all COPC carcinogens	unitless	
Cancer $Risk_i$	Individual lifetime cancer risk through indirect exposure to COPC carcinogen *i*	unitless	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table C-1-7. The value for this variable will vary for each exposure pathway. Uncertainties associated with this variable include the following: (1) Default factors for exposure frequency and exposure duration are assumed to represent the highest exposure that is reasonably expected to occur at a site. In practice, intakes are estimated by combining upper-bound (90th to 95th percentile) values for these exposure variables, but not for other parameters. This assumption is likely to overestimate intakes and the *Cancer* $Risk_i$. (2) Slope factors are used to estimate an upper-bound lifetime probability of an individual developing cancer as a result of exposure to a particular level of a potential carcinogen; and are accompanied by the weight of evidence classification to indicate the strength of the evidence that the agent is a human carcinogen. This classification has the potential to over- or underestimate risk. (3) Risk at low exposure levels is difficult to measure directly either by animal experiments or by epidemiological studies. The development of a cancer slope factor generally entails applying a model to the available data set and using the model to extrapolate from the relatively high doses administered to experimental animals (or the exposures noted in epidemiological studies) to lower exposure levels expected for human contact in the environment. This approach is likely to overestimate *CSF*. The uncertainties associated with this variable are COPC- and site-specific.

TABLE C-1-10

TOTAL HAZARD INDEX: NONCARCINOGENS

(Page 1 of 1)

Description

For non-cancer health effects, hazard quotient for all COPCs, regardless of target organs, are summed to calculate a total *hazard index*. Uncertainties associated with this equation include the following:

(1) The assumption that different COPCs affect the same target organ to produce an adverse health effect, ignoring potential antagonistic or synergistic effects or disparate effects on different target organs, may overestimate the total hazard index.

(2) Total hazard index assumes that a single individual in the exposure scenario is exposed to site-related contaminants at estimated exposure concentrations by all pathways that make up the scenario. It is unlikely, however, that a single individual will be exposed by each pathway in the exposure media. This assumption may overestimate the total hazard index.

Equation

$$Total\ Hazard\ Index = \sum_j HI_j$$

$$HI = \sum_i HQ_i$$

Variable	Description	Units	Value
Total Hazard Index	Total individual hazard index for all COPCs across all exposure pathways	unitless	
HI_j	Hazard Index for exposure pathway j	unitless	**Varies** This variable is COPC- and site-specific. The value for this variable will vary for each exposure pathway. Uncertainties associated with this variable are site-specific.
HQ_i	Hazard Quotient for COPC i	unitless	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table C-1-8. The value for this variable will vary for each exposure pathway. Uncertainties associated with this variable are site-specific.

TABLE C-1-11

SEGREGATED HAZARD INDEX FOR SPECIFIC ORGAN EFFECTS: NONCARCINOGENS

Description

For non-cancer health effects, hazard quotients are added across COPCs when they target the same organ to calculate a segregated *hazard index*. See Appendix A-2 for identification of noncarcinogens and their associated target organ. Since segregation by critical effect requires the identification of all major effects, information in Appendix A-2 may not always represent the most current and complete information on COPC-specific major effects. Therefore, Appendix A-2 may require supplemental information about COPC-specific major effects. Uncertainties associated with this equation include the following:

(1) Target organ segregation is dependent upon the critical effect. Segregation by critical effect requires the identification of all major effects, not just those seen at higher doses. The segregation process may over- or underestimate the *hazard index.*

Equation

$$HI_j = \sum_i HQ_i$$

Variable	Description	Units	Value
HI_j	Hazard index for exposure pathway *j*	unitless	
HQ_i	Hazard quotient for COPC *i*	unitless	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table C-1-8. The value for this variable will vary for each exposure pathway. The following uncertainty is associated with this variable: (1) Default factors for exposure frequency and exposure duration are assured to represent the highest exposure that is reasonably expected to occur as a site. In practice, intakes are estimated by combining upper-bound (90th to 95th percentile) values for these exposure variables, but not for other parameters. This equation is likely to overestimate intakes and HI_j. (2) Adverse health effects at low exposure levels are difficult to either directly either by animal experiments or by epidemiological studies. The development of *RfD*s generally entails applying uncertainty factors to extempolate from the results of studies using high exposure doses to lower exposure doses expected for human contact in the environment. This approach is unlikely to underestimate and likely overestimate HI_j. The uncertainties associated with this variable are COPC- and site-specific and will vary for each exposure pathway.

TABLE C-2-1

INHALATION CANCER RISK FOR INDIVIDUAL CHEMICALS: CARCINOGENS

Description

This equation calculates the excess lifetime individual cancer risk from the average daily intake via inhalation of a COPC carcinogen. Uncertainties associated with this equation include:

(1) COPC-specific *Inhalation CSF* values are unlikely to underestimate, and may overestimate, the carcinogenic potential of COPCs because of the choice of mathematical models and the use of uncertainty factors on the estimation of these values.
(2) COPC-specific *URF* values are unlikely to underestimate, and may overestimate, the carcinogenic potential of a COPC because of the choice of mathematical models and the use of uncertainty factors in the estimation of these values.
(3) The uncertainty associated with the variable C_a are largely site-specific.
(4) The uncertainties associated with the remaining variables in the equation in Table C-2-1, *IR, ET, EF, ED, BW*, and *AT* are not expected to be significant.

Equation

$$Cancer\ Risk_{inh(i)} = ADI \cdot CSF_{inh(i)}$$

$$ADI = \frac{C_a \cdot IR \cdot ET \cdot EF \cdot ED \cdot 0.001\ mg/\mu g}{BW \cdot AT \cdot 365\ day/yr}$$

$$CSF_{inh(i)} = \frac{URF \cdot 70\ kg \cdot 10^3\ \mu g/mg}{20\ m^3/day}$$

Variable	Description	Units	Value
$Cancer\ Risk_{inh(i)}$	Individual lifetime cancer risk through direct inhalation of COPC carcinogen *i*	unitless	
ADI	Average daily COPC intake via inhalation	mg COPC/ kg-day	

Variable	Description	Units	Value
Inhalation CSF	Inhalation Cancer Slope Factor	$(mg/kg\text{-}day)^{-1}$	**Varies** This variable is COPC-specific, and should be determined from the COPC tables in Appendix A-3 . Uncertainty associated with this variable includes: Inhalation COPC-specific carcinogenic slope factors (*Inhalation CSF*) are generally estimated by fitting the results of studies conducted on laboratory animals with a mathematical model. The model generally recommended by U.S. EPA is the lineraized multistage (LMS) model; U.S. EPA's position on assessing carcinogenic potential was recently updated (U.S. EPA 1996b). This model assumes that there is no "safe dose" or threshold below which a COPC causing cancer and higher doses will no longer cause cancer in exposed individuals. In other words, any exposure to a carcinogen may, through a series of stages, result in the formation of cancer in an exposed individual. Also, before fitting the results with the LMS model, the results are adjusted by the application of a series of uncertainty factors. The application of uncertainty factors follows the underlying assumption that humans are, or may be, as sensitive or more sensitive to the carcinogenic effects of COPCs than the laboratory COPCs that were tested. As a result, of both the choice of models and the use of uncertainty factors, COPC-specific *Inhalation CSF* are unlikely to underestimate a COPC's potential for causing cancer.

Variable	Description	Units	Value
URF	Inhalation Unit Risk Factor	$(\mu g/m^3)^{-1}$	**Varies** This variable is COPC-specific, and should be determined from the COPC tables in Appendix A-3. The following general uncertainty is associated with this variable: COPC-specific inhalation unit risk factors (*URFs*) are generally estimated by fitting the results of studies conducted on laboratory animals with a mathematical model. The model generally recommended by U.S. EPA is the linearized multistage (LMS) model. U.S. EPA's position on assessing carcinogenic potential was recently updated (U.S. EPA 1996b). The LMS model assumes that there is no "safe dose" or threshold below which a COPC causing cancer at higher doses will no longer cause cancer in expected individuals. In other words, any exposure to a carcinogen may, through a series of stages, cause cancer in an exposed individual. Also, before the results are fitted with the LMS model, series of uncertainty factors are applied to the results. The application of uncertainty factors follows the underlying assumption that humans are, or may be, as sensitive or more sensitive to the carcinogenic effects of COPCs than the laboratory animals that were tested. As a result of the choice of models and the use of uncertainty factors, COPC-specific *URFs* are unlikely to underestimate a COPC's potential for causing cancer.
C_a	Total COPC air concentration	$\mu g/m^3$	**Varies** This variable is COPC- and site-specific, and is calculated using the equation in Table B-5-1. Uncertainty associated with this variable includes: Calculated assuming a default S_T value for background plus local sources, rather than a S_T value for urban sources. If a specific site is located in an urban area, the use of the letter S_T value may be more appropriate. Specifically, the S_T value for urban sources is about one order of magnitude greater than the S_T value for background plus local sources and would result in a lower calculated F_v value; however, the F_v value is likely to be only a few percent lower.

Variable	Description	Units	Value
IR	Inhalation rate	m^3/hr	**0.30 or 0.63** This variable is site-specific. U.S. EPA OSW recommends using default values of 0.63 (adults) and 0.30 (children) in the absence of site-specific information. The recommended adult value is consistent with U.S. EPA (1991) and U.S. EPA (1994a). The recommended child value is greater than the inhalation rate proposed on U.S. EPA (1994b)— 0.18 m^3/hr based simply on the adult inhalation rate multiplied by the ratio of child to adult body weight (15 kg/70 kg)—but is consistent with U.S. EPA (1997) and U.S. EPA (1996c). Uncertainty associated with this variable includes: The recommended inhalation rates do not consider individual respiratory or activity differences. Therefore, based on the individual and the activities that individual is engaged in, the recommended inhalation rates may under-or overestimate the actual rates. However, the degree of under-or overestimation is not expected to be significant.
ET	Exposure time	hrs/day	**24** This variable is site-specific. U.S. EPA OSW recommends the use of this default value in the absence of site-specific data. Uncertainty associated with this variable includes: The recommended *ET* value assumes that an individual remains at a specific location 24 hours per day. In reality this is likely to be true only for a minority of the population including young children, their caregivers, and elderly or other individual who are sick. Therefore, this recommended value contributes to a degree of overestimation for much of the population. However, it must be noted that though an individual may not always be at a single location, that individual may continue to be exposed to emissions at an alternate location.

TABLE C-2-1

INHALATION CANCER RISK FOR INDIVIDUAL CHEMICALS: CARCINOGENS

Variable	Description	Units	Value
EF	Exposure frequency	days/yr	**350** This variable is site-specific. U.S. EPA OSW recommends the use of this default value in the absence of site-specific data. This value is based on U.S. EPA (1991) and is consistent with U.S. EPA (1994b). Uncertainties associated with this variable include: (1) This exposure frequency is a single value that represents the most frequent exposure that is reasonably expected to occur at a site with two weeks of vacation. This recommended value may overestimate *EF* for individuals who are away from their home for more than two weeks each year. On the other had, some individuals such as subsistence farmers, may remain at their home (or farm) for more than 350 days per year. In either case, the degree of over- or underestimation is not expected to be significant in most cases.
ED	Exposure duration	yr	**6, 30, or 40** This variable is site-specific. Consistent with U.S. EPA (1994b), U.S. EPA OSW recommends the use of the following default values. <u>Exposure Scenario</u> — <u>*ED*</u> Subsistence Farmer — 40 — (U.S. EPA 1994a) Subsistence Farmer Child — 6 — (U.S. EPA 1989) Subsistence Fisher — 30 — (U.S. EPA 1994a) Subsistence Fisher Child — 6 — (U.S. EPA 1989) Adult Resident — 30 — (U.S. EPA 1989) Child Resident — 6 — (U.S. EPA 1989) Uncertainties associated with this variable include: (1) These exposure durations are single values that represent the highest exposure that is reasonably expected to occur at a site. These values may overestimate *ED* for some individuals.

TABLE C-2-1

INHALATION CANCER RISK FOR INDIVIDUAL CHEMICALS: CARCINOGENS

Variable	Description	Units	Value
BW	Body weight	kg	**15 or 70** This variable is site-specific. U.S. EPA OSW recommends using default values of 70 (adults) and 15 (children) in the absence of site-specific information. These default values are consistent with U.S. EPA (1991; 1994b). Uncertainties associated with this variable include: (1) These body weights represent the average weight of an adult and child. However, depending on the site, the body weights may be higher or lower. These default values may overestimate or underestimate actual body weights. However, the degree of under- or overestimation is not expected to be significant.
AT	Averaging time	yr	**70** This variable is site-specific. U.S. EPA OSW recommends the use of this default value in the absence of site-specific data. This default value is consistent with U.S. EPA (1989), U.S. EPA (1991), and U.S. EPA (1994b). Uncertainties associated with this variable include: (1) The recommendation for averaging time may not accurately represent site-specific time; specifically this single value may under- or overestimate the length of an average adult lifetime.

REFERENCES AND DISCUSSION

U.S. EPA. 1989. *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A).* Interim Final. Office of Emergency and Remedial Response. EPA/540/1-89/002. December.

This document is cited as the reference source document of the exposure duration for adult and child residents. U.S. EPA assumes that the recommended exposure duration for the child resident may also reasonably be applied to the subsistence farmer child and to the subsistence fisher child. This document is also cited as reference source document for the averaging time for carcinogens.

U.S. EPA. 1991. *Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors.* Office of Solid Waste and Emergency Response. OSWER Directive 9285.6-03. Washington, D.C. March 21.

This document is cited as the reference source document of the exposure frequency and body weight variables.

U.S. EPA. 1994a. *Estimating Exposure to Dioxin-like Components - Volume III: Site-Specific Assessment Procedure.* Review Draft. Office of Research and Development. Washington D.C. EPA/600/6-88/005Cc. June.

This document is cited by U.S. EPA (1994b) as the same document for the recommended default exposure duration (*ED*) values for the subsistence farmer and subsistence fisher. The *ED* value of 40 years recommended for both the subsistence farmer and the subsistence fisher is based on the assumption that "farmers live in one location longer than the general population".

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document recommends the following:

- An adult inhalation rate of 20 m^3/day (0.83 m^3/hr) an a child inhalation rate of 7.2 m^3/day (0.3 m^3/hr)—based on multiplying the adult rate by the ratio of child to adult body weight (15 kg/70 kg).
- An exposure frequency of 350 days per year
- Receptor-specific exposure duration values as presented in U.S. EPA (1994a)—subsistence fisher (40 years) and subsistence farmer (40 years) and U.S. EPA (1989)—adult resident (30 years) and child resident (6 years)
- Adult and child body weights of 70 kg and 15 kg, respectively
- An averaging time, *AT*, of 70 years

U.S. EPA. 1994c. *Health Effects Assessment Summary Tables. Annual Update.* OHEA-ECAO-CIN-909. Environmental Criteria and Assessment Office, Office of Research and Development Cincinnati, Ohio.

This document represent U.S. EPA's secondary source of *Inhalation CSF* values.

U.S. EPA. 1996a. "Integrated Risk Information System (IRIS)". *Database on Toxicity Information Network (TOXNET).*

This reference represents U.S. EPA's primary source of *Inhalation CSF* values and other toxicity factors. This reference is updated periodically and should be reviewed prior to preparing a risk assessment.

U.S. EPA. 1996b. "Proposed Guidelines for Carcinogenic Risk Assessment." *Federal Register.* 61 FR 31667. Volume 61. Number 120. June 20.

This document proposes new guidelines for assessing the carcinogenicity of COPCs.

U.S. EPA. 1996c. "EPA Region IX Preliminary Remediation Goals (PRGs) -- 1996." August 1.

This document recommends a reasonable maximum exposure (RME) inhalation rate for children of 10 m^3/day, citing U.S. EPA (1989) as its source of information.

U.S. EPA. 1997. *Exposure Factors Handbook.* Office of Research and Development. EPA/600/P-95/002F. August.

This document recommends an "average" child inhalation of 7.17 m^3/day (0.30 m^3/hr), and an "average" adult inhalation rate of 15.2 m^3/day (0.63 m^3/hr).

TABLE C-2-2

INHALATION HAZARD QUOTIENT FOR COPCS: NONCARCINOGENS

Description

This equation calculates the *HQ* for inhalation exposures to COPCs that have noncancer health effects. Uncertainties associated with this equation include the following:

(1) COPC-specific reference concentrations (*RfC*) are unlikely to underestimate a COPC's potential for causing adverse health effects.
(2) Most of the uncertainties associated with the variables in the equation in Table B-5-1 (used to calculate C_a), specifically those associated with the variables *Q, Cyv*, and *Cyp*, are site-specific.
(3) The uncertainties associated with the remaining variables in the equation in Table C-2-2, *IR, ET, EF, ED, BW*, and *AT* are not expected to be significant.

Equation

$$HQ_{inh(i)} = \frac{ADI}{RfD}$$

$$ADI = \frac{C_a \cdot IR \cdot ET \cdot EF \cdot ED \cdot 0.001\ mg/\mu g}{BW \cdot AT \cdot 365}$$

$$RfD = \frac{RfC \cdot 20\ m^3/day}{70\ kg}$$

Variable	Description	Units	Value
$HQ_{inh(i)}$	Hazard quotient for direct inhalation of COPC noncarcinogen *i*	unitless	
ADI	Average daily COPC intake via inhalation	mg COPC/ kg-day	
C_a	Total COPC air concentration	µg/m^3	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-5-1.

TABLE C-2-2

INHALATION HAZARD QUOTIENT FOR COPCS: NONCARCINOGENS

Variable	Description	Units	Value
RfD	Reference Dose	mg/kg-day	**Varies** This variable is COPC-specific, and should be determined from the COPC tables in Appendix A-3. The following uncertainty is associated with this variable: A chronic RfD is an estimate of a daily exposure level for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime. Chronic RfDs are specifically developed to be protective for long-term exposure (from 7 years to a lifetime) to a compound. COPC-specific RfDs are unlikely to underestimate a chemical's potential for causing adverse health effects.
RfC	Reference concentration	mg/m^3	**Varies** This variable is COPC-specific, and should be determined from the COPC tables in Appendix A-3. The following uncertainty is associated with this variable: COPC *RfC*s are generally estimated by applying a series of uncertainty factors to the results of studies conducted on laboratory animals. The application of uncertainty factors follows the underlying assumption that humans are, or may be, as sensitive or more sensitive to the harmful effects of COPCs than the laboratory animals that were tested. *RfC*s are designed to ensure that the general public, including sensitive subpopulations, will not experience adverse health effects as a result of exposure to a COPC at its *RfC*. As a result, COPC-specific *RfC*s are unlikely to underestimate a COPC's potential for causing adverse health effects.
IR	Inhalation rate	m^3/hr	**0.30 or 0.63** This variable is site-specific. U.S. EPA OSW recommends using default values of 0.63 (adults) and 0.30 (children) in the absence of site-specific information. The recommended adult value is consistent with U.S. EPA (1991) and U.S. EPA (1994c). The recommended child value is greater than the inhalation rate proposed in U.S. EPA (1994b)— 0.18 m^3/hr based simply on the adult inhalation rate multiplied by the ratio of child to adult body weight (15 kg/70 kg)—but is consistent with U.S. EPA (1997). Uncertainty associated with this variable includes: The recommended inhalation rates do not consider individual respiratory or activity differences. Therefore, based on the individual and the activities that individual is engaged in, the recommended inhalation rates may under-or overestimate the actual rates. However, the degree of under-or overestimation is not expected to be significant.

TABLE C-2-2

INHALATION HAZARD QUOTIENT FOR COPCS: NONCARCINOGENS

Variable	Description	Units	Value
ET	Exposure time	hrs/day	**24** This variable is site-specific. U.S. EPA OSW recommends the use of this default value in the absence of site-specific data. Uncertainty associated with this variable includes: The recommended *ET* value assumes that an individual remains at a specific location 24 hours per day. In reality this is likely to be true only for a minority of the population including young children, their caregivers, and elderly or other individual who are sick. Therefore, this recommended value contributes to a degree of overestimation for much of the population. However, it must be noted that though an individual may not always be at a single location, that individual may continue to be exposed to combustion emissions at an alternate location.
EF	Exposure frequency	days/yr	**350** This variable is site-specific. U.S. EPA OSW recommends the use of this default value in the absence of site-specific data. This value is based on U.S. EPA (1991) and is consistent with U.S. EPA (1994b). Uncertainties associated with this variable include: (1) This exposure frequency is a single value that represents the most frequent exposure that is reasonably expected to occur at a site with two weeks of vacation. This recommended value may overestimate *EF* for individuals who are away from their home for more than two weeks each year. On the other had, some individuals such as subsistence farmers, may remain at their home (or farm) for more than 350 days per year. In either case, the degree of over- or underestimation is not expected to be significant in most cases.

TABLE C-2-2

INHALATION HAZARD QUOTIENT FOR COPCS: NONCARCINOGENS

Variable	Description	Units	Value
ED	Exposure duration	yr	**6, 30, or 40** This variable is site-specific. Consistent with U.S. EPA (1994b) and NC DEHNR (1997), U.S. EPA OSW recommends the use of the following default values. <u>Exposure Scenario</u> — <u>*ED*</u> Subsistence Farmer — 40 — (U.S. EPA 1994c) Subsistence Farmer Child — 6 — (U.S. EPA 1989) Subsistence Fisher — 30 — (U.S. EPA 1994c) Subsistence Fisher Child — 6 — (U.S. EPA 1989) Adult Resident — 30 — (U.S. EPA 1989) Child Resident — 6 — (U.S. EPA 1989) Uncertainty associated with this variable includes: These exposure durations are single values that represent the highest exposure that is reasonably expected to occur at a site. These values may overestimate *ED* for some individuals.
BW	Body weight	kg	**15 or 70** This variable is site-specific. U.S. EPA OSW recommends using default values of 70 (adults) and 15 (children). These default values are consistent with U.S. EPA (1991; 1994c). Uncertainty associated with this variable includes: These body weights represent the average weight of an adult and child. However, depending on the site, the body weights may be higher or lower. These default values may overestimate or underestimate actual body weights. However, the degree of under- or overestimation is not expected to be significant.
365	Units conversion factor	day/yr	
AT	Averaging time	yr	**6, 30, or 40** This variable is site-specific and related to *ED*. Specifically, the *AT* for noncarcinogens is numerically the same as the *ED*. This default value is consistent with U.S. EPA (1989), U.S. EPA (1991), and U.S. EPA (1994c). Uncertainty associated with this variable includes: The recommendation for averaging time may not accurately represent site-specific time; specifically this single value may under- or overestimate the length of an average adult lifetime.

TABLE C-2-2

INHALATION HAZARD QUOTIENT FOR COPCS: NONCARCINOGENS

REFERENCES AND DISCUSSION

U.S. EPA. 1989. *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A).* Interim Final. Office of Emergency and Remedial Response. EPA/540/1-89/002. December.

This document is cited as the reference source document of the exposure duration for adult and child residents. U.S. EPA assumes that the recommended exposure duration for the child resident may also reasonably be applied to the subsistence farmer child and to the subsistence fisher child.

U.S. EPA. 1991. *Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors.* Office of Solid Waste and Emergency Response. OSWER Directive 9285.6-03. Washington, D.C.

This document is cited as the reference source document of the body weight variables.

U.S. EPA. 1994a. IRIS. *Database on the TOXNET.*

This document is U.S. EPA's primary source of *RfCs* and other toxicity factors. This document is updated periodically and should be reviewed prior to preparing a risk assessment.

U.S. EPA. 1994b. *Estimating Exposure to Dioxin-like Components - Volume III: Site-Specific Assessment Procedure.* Review Draft. Office of Research and Development. Washington D.C. EPA/600/6-88/005Cc. June.

This document is cited by U.S. EPA (1994b) as the same document for the recommended default exposure duration (*ED*) values for the subsistence farmer and subsistence fisher. The *ED* value of 40 years recommended for both the subsistence farmer and the subsistence fisher is based on the assumption that "farmers live in one location longer than the general population".

U.S. EPA. 1994c. *Revised Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document recommends the following:

- An adult inhalation rate of 20 m^3/day (0.83 m^3/hr).
- An exposure frequency of 350 days per year
- Receptor-specific exposure duration values as presented in U.S. EPA (1994a)—subsistence fisher (40 years) and subsistence farmer (40 years) and U.S. EPA (1989)—adult resident (30 years) and child resident (6 years)
- Adult and child body weights of 70 kg and 15 kg, respectively

U.S. EPA. 1995. *Health Effects Assessment Summary Tables.* Annual Update. OHEA-ECAO-CIN-909. Environmental Criteria and Assessment Office. Office of Research and Development. Cincinnati, Ohio.

This document is U.S. EPA's secondary source of *RfCs* and other toxicity factors. This document is updated periodically and should be reviewed prior to preparing a risk assessment.

U.S. EPA. 1997. *Exposure Factors Handbook.* Office of Research and Development. EPA/600/P-95/002F. August.

TABLE C-2-3

TOTAL INHALATION CANCER RISK: CARCINOGENS

This document recommends an "average" child inhalation of 7.17 m^3/day (0.30 m^3/hr), and recommends an "average" adult inhalation rate of 15.2 m^3/day (0.63 m^3/hr).

Description

Cancer risk to the individual via inhalation are added across all COPCs that are carcinogenic via the direct inhalation route of exposure.

Uncertainties associated with this equation include the following:

(1) *Total Cancer Risk* assumes that different carcinogens affect the same target organ to produce a cancer response, ignoring potential antagonistic or synergistic effects or disparate effects on different target organs. This assumption may overestimate *Total Cancer Risk.*

(2) The summation of cancer risks across multiple COPCs means that the uncertainties associated with estimating cancer risk for each COPC are also summed. This means *Total Cancer Risk*, as defined below, is unlikely to be overestimated.

Equation

$$Total\ Cancer\ Risk_{inh} = \sum_{i} Cancer\ Risk_{inh(i)}$$

Variable	Description	Units	Value
Total Cancer Risk$_{inh}$	Total individual lifetime cancer risk through direct inhalation of all COPC carcinogens	unitless	
Cancer Risk$_{inh(i)}$	Individual lifetime cancer risk through direct inhalation for COPC carcinogen *i*	unitless	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table C-2-1. The equation in Table C-2-2 is used if the carcinogenic slope factor is available for the COPC. Uncertainties associated with this variable include the following: (1) COPC-specific *URF* values are unlikely to underestimate, and may overestimate, the carinogenic potential of COPCs because of the mathematical models and the use of uncertainty factors in the estimation of these values. (2) Most of the uncertainties associated with the variables used to calculate C_a, specifically *Q, Cyv*, and *Cyp*, are site-specific.

TABLE C-2-4

HAZARD INDEX FOR INHALATION: NONCARCINOGENS

(Page 1 of 1)

Description

For non-cancer health effects, *HQs* for inhalation exposures are added across COPCs when they target the same organ to obtain an *HI* for the target organ. See Appendix A-2 for target organs and Appendix A-3 for COPC-specific inhalation *RfCs* and for identification of COPCs that cause noncarcinogenic effects via the inhalation route of exposure and their associated target organs. Uncertainties associated with this equation include the following:

(1) The summation of noncarcinogenic hazards across multiple COPCs means that the uncertainties associated with estimating hazards for each COPC (see *HQ* below) are also summed. This means that the total noncarcinogenic hazard, as defined below, is unlikely to be overestimated.

(2) As defined below, the *HI* sums the *HQs* for all COPCs to which a receptor is potentially exposed. Ideally, *HQs* should be summed only for COPCs that affect the same target organs and systems. To the extent that COPCs affect different target organs, summing their associated *HQs* will overestimate the actual *HI*.

Equation

$$HI_{inh} = \sum_i HQ_i$$

Variable	Description	Units	Value
$HI_{inh(j)}$	Hazard index for target organ effect *j* through direct inhalation of all COPCs	unitless	
$HQ_{inh(i)}$	Hazard quotient for direct inhalation of COPC *i*	unitless	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table C-2-3. Uncertainties associated with this variable include the following: (1) COPC-specific *RfCs* are unlikely to underestimate a COPC's potential for causing adverse health effects. 2) Most of the uncertainties associated with the variables used to calculate C_a, specifically *Q*, *Cyv*, and *Cyp*, are site-specific.

TABLE C-3-1

CONCENTRATION OF DIOXINS IN BREAST MILK

Description

This equation calculates the concentration of dioxins in milkfat of breast milk. Uncertainties associated with this equation include the following:

(1) The most significant uncertainties associated with this equation are those associated with the variable *m*. Because *m* is calculated as the sum of numerous potential intakes, estimates of *m* incorporate uncertainties associated with each exposure pathway. Therefore, *m* may be under- or overestimated. Every effort should be made to limit and characterize the uncertainties associated with this variable.

(2) This equation assumes that the concentration of dioxin in breast milkfat is the same as in maternal fat. To the extent that this is not the case, uncertainty is introduced.

Equation

$$C_{milkfat} = \frac{m \cdot 1\times10^{9} \cdot h \cdot f_1}{0.693 \cdot f_2}$$

Variable	Description	Units	Value
$C_{milkfat}$	Concentration of dioxin in milk fat of breast milk for a specific exposure scenario	pg COPC/kg milk fat	
m	Average maternal intake of dioxin for each adult exposure scenario	mg COPC/kg BW-day	**Varies** This variable is COPC- and site-specific and is equal to the total daily intake of dioxin (*I*), which is calculated using the equation in Table C-1-6 for each adult exposure scenario. The following uncertainty is associated with this variable: (1) The uncertainty associated with this variable may be significant, because this uncertainty represents the sum of all uncertainties associated with each of the potential exposure pathways. To gauge the potential magnitude of the uncertainty associated with this variable, estimated *m* values should be compared to values reported in the literature.
1×10^{9}	Units conversion factor	pg/mg	

TABLE C-3-1

CONCENTRATION OF DIOXINS IN BREAST MILK

Variable	Description	Units	Value
h	Half-life of dioxin in adults	days	**2,555** This variable is COPC- and site-specific. U.S. EPA OSW recommends the use of this default value, consistent with U.S. EPA (1994a) and U.S. EPA (1994b). The following uncertainty is associated with this variable: As discussed in U.S. EPA (1994a), the half-life may vary from about 5 to 7 years for 2,3,7,8-TCDD. Use of the upper end of the range is conservative. Based on the work of Schecter (1991), and Schlatter (1991), as discussed in U.S. EPA (1994a), the value of *h* may vary by almost one order of magnitude (1.1 to 50) for different dioxin and furan congeners around the value of 7 proposed for 2,3,7,8-TCDD. The differences are largely the result of differences in absorption. However, if the average material intake of dioxin is calculated in terms of *TEQ*s, the use of a single *h* value based on 2,3,7,8-TCDD is assumed to be reasonable.
f_1	Fraction of ingested dioxin that is stored in fat	unitless	**0.9** This variable is COPC- and site-specific. U.S. EPA OSW recommends the use of this default value, consistent with U.S. EPA (1994b). The source of this value is U.S. EPA (1994a).
f_2	Fraction of mother's weight that is fat	unitless	**0.3** This variable is COPC-specific. U.S. EPA OSW recommends the use of this default value, consistent with U.S. EPA (1994a) and U.S. EPA (1994b). The source of this value is U.S. EPA (1994a). The following uncertainty is associated with this variable: Although this single value clearly does not adequately represent all potentially exposed women of childbearing age, the average uncertainty associated with this value is assumed to be minimal.

REFERENCES AND DISCUSSION

Schecter, A. 1991. "Dioxins and Related Chemicals in Humans and in the Environment." In: *Biological Basis for Risk Assessment of Dioxins and Related Compounds*: Gallo, M.; Schenplein, R; Van Der Heijden, K. Eds; Banbury Report 35, Cold Spring Harbor Laboratory Press.

This document is cited by U.S. EPA (1994a) as the source of information related to the metabolism of dioxin and related compounds, in addition to concentrations of various congeners in adipose tissue.

Schlatter, C., 1991. "Data on Kinetics of PCDDs and PCDFs as a Prerequisite for Human Risk Assessment." In: *Biological Basis for Risk Assessment of Dioxins and Related Compounds*; Gallo, M; Schenplein, R; Van Der Heijder, K., eds. Banbury Report 35, Cold Spring Harbor Laboratory press.

This document is cited by U.S. EPA (1994a) as a source of a method of estimating the half-life of dioxin-related compounds, based on uptake data relative to 2,3,7,8-TCDD. U.S. EPA (1994a) proposed the following equation, based on this document:

$$C_{TCDD} = \frac{D_{TCDD} \cdot t_{1/2}, TCDD \cdot V}{\ln 2}$$

where

C_{TCDD}	=	Concentration of TCDD in body
D_{TCDD}	=	Daily intake of TCDD
$t_{1/2}$, $TCDD$	=	Half-life of TCDD in body
V	=	Volume of body compartment

Smith, A.H. 1987. "Infant Exposure Assessment for Breast Milk Dioxins and Furans Derived from Waste Incineration Emissions." *Risk Analysis.* 7(3) 347-353.

This document is cited by U.S. EPA (1994a) as the source of the equation in Table C-3-1 and the recommended values for h (2,555 days), f_1 (0.9), and f_2 (0.3). This document assumes that the concentration of dioxins in breast milkfat is the same as in maternal fat.

U.S. EPA. 1994a. *Estimating Exposure to Dioxin-Like Compounds. Volume II: Properties, Sources, Occurrence, and Background Exposures. Review Draft.* Office of Research and Development. EPA/600/6-88/0055Cb. Washington, D.C. June.

This document cites Smith (1987) as the source for half of the recommended values for the life of dioxin for adults (h), proportion of ingested dioxin that is stored in fat (f_1), and proportion of mother's milk that is fat (f_2).

TABLE C-3-2

AVERAGE DAILY DOSE TO THE EXPOSED INFANT

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Waste. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document recommends the use of the equation in Table C-3-1 and values for the variables in this equation: h (2,555 days), f_1 (0.9), and f_2 (0.3).

TABLE C-3-2

AVERAGE DAILY DOSE TO THE EXPOSED INFANT

Description

This equation calculates the average daily dose for an infant exposed to contaminated breast milk. Uncertainty associated with this equation includes the following:

The most significant uncertainty associated with this equation is the selection of a value for averaging time (*AT*). As stated in U.S. EPA (1994a), "Little agreement exists regarding the appropriate choice of an averaging time for less than lifetime exposures. This is especially true for cases where exposure is occurring in a particularly sensitive developmental period."

Use of an averaging time (*AT*) of 1 year is appropriate for assessing noncarcinogenic effects. However, use of this value may overestimate a lifetime average appropriate for assessing carcinogenic risk by almost two orders of magnitude (70/1).

Equation

$$ADD_{infant} = \frac{C_{milkfat} \cdot f_3 \cdot f_4 \cdot IR_{milk} \cdot ED}{BW_{infant} \cdot AT}$$

Variable	Description	Units	Value
ADD_{infant}	Average daily dose for infant exposed to contaminated breast milk	pg COPC/kg BW-day	
$C_{milkfat}$	Concentration of COPC in milk fat of breast milk for a specific exposure scenario	pg COPC/kg milkfat	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table C-3-1. The following uncertainty is associated with this variable: • The most significant uncertainties associated with the calculation of this variable are those associated with the variable *m* and the estimate of $C_{milkfat}$. Uncertainties associated with *m* represent a sum of the various uncertainties associated with each of the potential exposure pathways (see the equation in Table C-1-6).
f_3	Fraction of mother's breast milk that is fat	unitless	**0.04** This variable is COPC- and site-specific. U.S. EPA OSW recommends the use of this default value, consistent with U.S. EPA (1994a) and U.S. EPA (1994b). As cited in U.S. EPA (1994a), the source of this variable value is Smith (1987). The uncertainty associated with this value is assumed to be minimal.

TABLE C-3-2

AVERAGE DAILY DOSE TO THE EXPOSED INFANT

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Variable	Description	Units	Value
f_4	Fraction of ingested COPC that is absorbed	unitless	**0.9** This variable is COPC- and site-specific. U.S. EPA OSW recommends the use of this default value, consistent with U.S. EPA (1994a),and U.S. EPA (1994b). As cited in U.S. EPA (1994a), the source of this variable value is Smith (1987). The uncertainty associated with this value is assumed to be minimal.
IR_{milk}	Ingestion rate of breast milk by the infant	kg/day	**0.8** This variable is COPC- and site-specific. U.S. EPA OSW recommends the use of this default value, consistent with U.S. EPA (1994a) and U.S. EPA (1994b). As cited in U.S. EPA (1994a), the source of this variable value is Smith (1987). The following uncertainty is associated with this variable: As reported in U.S. EPA (1994a), Smith (1987) reports that breast milk ingestion for 7- to 8-month-old infants ranged from 677 to 922 mL/day. Assuming a density of breast milk of slightly more than 1.0, the recommended value is about the midpoint of the reported ingestion rate, converted from milliliters per day to kilograms per day. Based on the reported ingestion range, the ingestion rate could vary by about 12 percent from the recommended value. This possible variance is not considered especially significant.
ED	Exposure duration	yr	**1.0** This variable is COPC- and site-specific. U.S. EPA OSW recommends the use of this default value, consistent with U.S. EPA (1994a) and U.S. EPA (1994b). The following uncertainty is associated with this variable: Some infants may nurse for more or less than the recommended 1 year. However, the average uncertainty associated with this variable value is not expected to be large.
BW_{infant}	Body weight of infant	kg	**10** U.S. EPA OSW recommends the use of this default value. As cited in U.S. EPA (1994a), this value is based on information presented by the National Center for Health Statistics (1987). The following uncertainty is associated with this variable: As reported in U.S. EPA (1994a), the National Center for Health Statistics (1987) reported mean body weights of 6- to 11-month-old and 1 year-old infants of 9.1 and 11.3 kilograms, respectively. Based on this information and an assumed 1-year *ED*, the uncertainty associated with this variable value is expected to be minimal.

TABLE C-3-2

AVERAGE DAILY DOSE TO THE EXPOSED INFANT

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Variable	Description	Units	Value
AT	Averaging time	yr	1 This variable is COPC- and site-specific. U.S. EPA OSW recommends the use of this default value, consistent with U.S. EPA (1994a) and U.S. EPA (1994b). The following uncertainty is associated with this variable: The uncertainty associated with this variable value is significant, as stated in U.S. EPA (1994a): "Little agreement exists regarding the appropriate choice of an averaging time for less than lifetime exposures. This is especially true for cases where exposure is occurring in a particularly sensitive developmental period." Use of an averaging time of 1 year is appropriate for assessing noncarcinogenic effects. However, use of this value may overestimate a lifetime average, appropriate for assessing carcinogenic risk, by almost two orders of magnitude (70/1).

REFERENCES AND DISCUSSION

National Center for Health Statistics. 1987.

Cited in U.S. EPA (1994a) as the source of the recommended BW_{infant} value of 10 kilograms. However, that document does not provide a complete reference for this document.

Smith., A.H. 1987. "Infant Exposure Assessment for Breast Milk Dioxins and Furans Derived from Waste Incineration Emissions." *Risk Analysis*. 7(3) 347-353.

This document is cited by U.S. EPA (1994a) as the source of the recommended values for the variables in the equation in Table C-3-2.

U.S. EPA. 1994a. *Estimating Exposure to Dioxin-Like Compounds. Review Draft.* Office of Research and Development. EPA/600/6-88/0055Cc. Washington ,D.C. June.

This document is cited as the original source of the fraction of fat in breast milk, fraction of ingested COPC that is absorbed, ingestion rate of breast milk, exposure duration, and body weight of infant.

U.S. EPA. 1994b. *Revised Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities.* Office of Emergency and Remedial Response. Office of Solid Waste. December 14.

This document recommends the use of the equation in Table C-3-2 and values for the variables in this equation: f_3 (0.04), f_4 (0.9), IR_{milk} (0.8 kg/day), *ED* (1 year), BW_{infant} (10 kg) , and *AT* (1 year).

TABLE C-4-1

ACUTE HAZARD QUOTIENT

Description

This equation calculates the acute hazard quotient *AHQ* for short term inhalation exposures to COPCs. Uncertainties associated with this equation include the following:

(1) Uncertainties may be associated with development components of COPC-specific acute inhalation exposure criteria (AIECs), including exposure group protected, exposure duration, and toxicity endpoint. Uncertainties are specific to each COPC's AIEC, and may under or overestimate the potential for causing adverse health effects.

(2) Most of the uncertainties associated with the variables in the equation in Table B-6-1 (used to calculate C_{acute}), specifically those associated with the variables *Q, Chv*, and *Chp*, are site-specific.

Equation

$$AHQ_{inh(i)} = \frac{C_{acute} \cdot 0.001}{AIEC}$$

Variable	Description	Units	Value
$AHQ_{inh(i)}$	Acute hazard quotient for inhalation of COPCs	unitless	
C_{acute}	Acute air concentration	µg/m³	**Varies** This variable is COPC- and site-specific, and is calculated by using the equation in Table B-6-1.
AIEC	COPC acute inhalation exposure criteria	mg/m³	**Varies** This variable is COPC-specific (see table in Appendix A-4) and determined following a hierarchal approach as discussed in Chapter 7 of the HHRAP. The following uncertainty is associated with this variable: Uncertainties may be associated with development components of COPC-specific acute inhalation exposure criteria (AIECs), including exposure group protected, exposure duration, and toxicity endpoint. Uncertainties are specific to each COPC's AIEC, and may under or overestimate the potential for causing adverse health effects.
0.001	Conversion factor	mg/µg	