# APPENDIX B
## ESTIMATING MEDIA CONCENTRATION EQUATIONS AND VARIABLE VALUES

DRINKING WATER AND FISH INGESTION EQUATIONS (cont'd)

**TABLE B-1-1**

**SOIL CONCENTRATION DUE TO DEPOSITION**
**(SOIL INGESTION EQUATIONS)**



**Description**

Use the equations in this table to calculate an average COPC soil concentration resulting from wet and dry deposition of particles and vapors to soil over the exposure duration. We recommend assuming that COPCs are incorporated only to a finite depth (the soil mixing zone depth, $Z_s$). Use the COPC soil concentration averaged over the exposure duration, represented by $Cs$, 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, we recommend using the highest annual average COPC soil concentration occurring during the exposure duration period for noncarcinogenic COPCs. The highest annual average COPC soil concentration would most likely 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) We assume that the time period for deposition of COPCs resulting from hazardous waste combustion is 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 won't 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) A value of zero for $T_1$ doesn't 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 below the 2 centimeters, resulting in lower concentrations within the 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) compared to other residues. This may underestimate $Cs$ and $Cs_{tD}$.

**Equation for Carcinogens**

Soil Concentration Averaged Over Exposure Duration

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

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

**TABLE B-1-1**

**SOIL CONCENTRATION DUE TO DEPOSITION**
**(SOIL INGESTION EQUATIONS)**



**Equation for Noncarcinogens**

Highest Annual Average Soil Concentration

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

where

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

For mercury modeling

$$Ds_{(Mercury)} = \frac{100 \cdot [0.48 Q_{(Total)}]}{Z_s \cdot BD} \cdot [F_{v_{(Hg^{2+})}} (Dydv + Dywv) + (Dydp + Dywp) \cdot [1 - F_{v_{(Hg^{2+})}}]$$

Use *0.48Q* for total mercury and $F_v = 0.85$ in the mercury modeling equation to calculate *Ds*. Apportion the calculated *Ds* value 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, assume elemental mercury deposition onto soils is negligible or zero. Evaluate elemental mercury for the direct inhalation pathway only (Table B-5-1).

$Ds_{(Hg2+)} = 0.98\ Ds_{(Mercury)}$
$Ds_{(MHG)} = 0.02\ Ds_{(Mercury)}$
$Ds_{(Hg0)} = 0.0$

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, $Hg^{2+}$) and methyl mercury provided in Appendix A-2, and (2) *Ds* ($Hg^{2+}$) and *Ds* (MHg) as calculated above.

**TABLE B-1-1**

**SOIL CONCENTRATION DUE TO DEPOSITION**
**(SOIL INGESTION EQUATIONS)**

**(Page 3 of 9)**

| 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**<br>U.S. EPA (1994a) and NC DEHNR (1997) recommend incorporating a deposition term into the *Cs* equation.<br><br>Uncertainties associated with this variable include the following:<br>(1) Five of the variables in the equation for *Ds (Q, Cywv, Dywv*, *Dydp*, and *Dywp*) are COPC- and site-specific. Values for these variables are estimated through modeling. The direction and magnitude of any uncertainties shouldn't be generalized.<br>(2) Based on the narrow recommended ranges, we expect uncertainties associated with *Vdv,* $F_v$, and *BD* to be low.<br>(3) Values for $Z_s$ vary by about one order of magnitude. Uncertainty is greatly reduced if you know whether soils are tilled or untilled. |
| *tD* | Time period over which deposition occurs (time period of combustion) | yr | **30**<br>U.S. EPA (1998) suggests that *tD* can be ≥ 30 years. We recommend using 30 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**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-1-2. The COPC soil loss constant is the sum of all COPC removal processes.<br><br>Uncertainty associated with this variable includes the following:<br>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)**

**(Page 4 of 9)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $T_2$ | Length of exposure duration | yr | **6, 30, or 40**<br>We recommend reasonable maximum exposure (RME) values for $T_2$:<br><br>Exposure Duration — RME — Reference<br>Child Resident, Farmer Child, Fisher Child — 6 years — U.S. EPA (1997b)<br>Adult Resident and Fisher — 30 years — U.S. EPA (1997b)<br>Farmer — 40 years — U.S. EPA (1994b)<br><br>U.S. EPA (1994c) recommended the following unreferenced values:<br><br>Exposure Duration — Years<br>Subsistence Farmer — 40<br>Adult Resident — 30<br>Subsistence Fisher — 30<br>Child Resident — 9<br><br>Uncertainties associated with this variable include the following:<br>(1) Exposure duration rates are based on historical mobility rates and may not remain constant. This assumption may overestimate or underestimate *Cs* and $Cs_{tD}$.<br>(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**<br>Consistent with U.S. EPA (1994c), we recommend a value of 0 for $T_1$.<br><br>The following uncertainty is associated with this variable:<br>A $T_1$ of 0 does not account for exposure that may have occurred from historical operations or emissions from burning hazardous waste. This may underestimate *Cs* and $Cs_{tD}$. |

**TABLE B-1-1**

**SOIL CONCENTRATION DUE TO DEPOSITION**
**(SOIL INGESTION EQUATIONS)**

**(Page 5 of 9)**

| Variable | Description | Units | Value |
|---|---|---|---|
| *100* | Units conversion factor | mg-cm$^2$/kg-cm$^2$ | |
| *Q* | COPC-specific emission rate | g/s | **Varies**<br>This variable is COPC- and site-specific. See Chapters 2 and 3 of the HHRAP for guidance on calculating this variable. Uncertainties associated with this variable are site-specific. |
| $Z_s$ | Soil mixing zone depth | cm | **2 to 20**<br>We recommend the following values for $Z_s$:<br><br>Soil — Depth (cm) — Reference<br>Untilled — 2 — Brzuzy et al. (1995)<br>Tilled — 20 — U.S. EPA (1998)<br><br>U.S. EPA (1992) recommended values of 1 cm (for untilled) and 20cm (for tilled soil). These values are consistent with U.S. EPA (1998), which further states that leaching soluble compounds might lead to movement below a 1-cm depth. A default value of 2 cm for untilled soil mixing depth is based on a study that profiled dioxin measurements within soil (Brzuzy et al. 1995). A default value of 20 cm for tilled soil mixing depth is based on U.S. EPA (1998).<br><br>The following uncertainties are associated with this variable:<br>(1) For soluble COPCs, leaching might lead to movement to below $Z_s$, resulting in lower concentrations within the $Z_s$. This uncertainty may overestimate *Cs* and $Cs_{tD}$.<br>(2) Deposition to hard surfaces may result in dust residues that have negligible dilution compared to other residues. This uncertainty may underestimate *Cs* and $Cs_{tD}$. |
| *BD* | Soil bulk density | g soil/cm$^3$ soil | **1.5**<br>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 (1998). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g soil/cm$^3$ soil, based on a mean value for loam soil obtained from Carsel et al. (1988). U.S. EPA (1998) stated that a value of 1.5 would suffice for most uses, if site-specific information was unavailable.<br><br>The following uncertainty is associated with this variable:<br>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-1-1**

**SOIL CONCENTRATION DUE TO DEPOSITION**
**(SOIL INGESTION EQUATIONS)**

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| Variable | Description | Units | Value |
|---|---|---|---|
| $F_v$ | Fraction of COPC air concentration in vapor phase | unitless | **0 to 1**<br>This variable is COPC-specific. We discuss this variable and offer COPC-specific values in Appendix A-2. The range is based on the values presented in Appendix A-2. Values are also presented in U.S. EPA (1994c) and NC DEHNR (1997).<br><br>$F_v$ 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).<br><br>The following uncertainties are associated with this variable:<br>(1) Our $F_v$ calculations assume a default $S_T$ value for background plus local sources, rather than an $S_T$ value for urban sources. If your site is located in an urban area, using 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.<br>(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 $F_v$. |
| *Dydv* | Unitized yearly average dry deposition from vapor phase | s/m$^2$-yr | **Varies**<br>This variable is COPC- and site-specific, and is determined by air modeling (see Chapter 3). Uncertainties associated with this variable are site-specific. |
| *Dywv* | Unitized yearly average wet deposition from vapor phase | s/m$^2$-yr | **Varies**<br>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**<br>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**<br>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-1-1**

**SOIL CONCENTRATION DUE TO DEPOSITION**
**(SOIL INGESTION EQUATIONS)**

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**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, Bidleman (1988) 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 Bidleman (1988), 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 $10^{-06}$ $cm^2/cm^3$ air (corresponds to background plus local sources) |
| $P^\circ_L$ | = | Liquid-phase vapor pressure of chemical (atm) (see Appendix A-2) |

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

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

| | | |
|---|---|---|
| $P^\circ_S$ | = | Solid-phase vapor pressure of chemical (atm) (see Appendix A-2) |
| $\frac{\Delta S_f}{R}$ | = | Entropy of fusion over the universal gas constant = 6.79 (unitless) |
| $T_m$ | = | Melting point of chemical (K) (see Appendix A-2) |
| $T_a$ | = | Ambient air temperature = 284 K (11°C) |

Brzuzy, L.P. and R.A. Hites. 1995. "Estimating the Atmospheric Deposition of Polychlorinated Dibenzo-p-dioxins and Dibenzofurans from Soils." *Environmental Science and Technology.* Volume 29. Pages 2090-2098.

This reference presents soil profiles for dioxin measurements.

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.

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.

Cited by U.S. EPA (1998) for the statement that *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.

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 using (1) a deposition term, *Ds*, and (2) COPC-specific $F_v$ 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 $F_v$ values.

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.

The External Review Draft of the MPE document (the final is U.S. EPA 1998) cites this document as the source of values for soil mixing zone depth, $Z_s$, for tilled and untilled soils.

U.S. EPA. 1993. *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.

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 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.

This document is a reference for the equation in Table B-1-1; it recommends using the following 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 et al. (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 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.

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 that range from 0.27 to 1 for organic COPCs
- Default soil bulk density value of 1.5 g soil/cm$^3$ soil, based on a mean for loam soil from Carsel et al. (1988)

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

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

U.S. EPA. 1998. *Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions (MPE)*. Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. 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-1-5 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**<br>This variable is COPC-specific. Values are available in the COPC tables in Appendix A-2.<br><br>"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.<br><br>The following uncertainty is associated with this variable:<br>COPC-specific values for *ksg* are determined empirically from field studies; no information is available on applying 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**<br>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), we recommend a default value of zero for *kse* because contaminated soil erodes both onto the site and away from the site.<br><br>Uncertainties associated with this variable include the following:<br>(1) The source of the equation in Table B-1-3 has not been identified.<br>(2) For soluble COPCs, leaching might lead to movement to below $Z_s$, resulting in lower concentrations within the $Z_s$. This uncertainty may overestimate *kse*.<br>(3) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) compared to other residues. This uncertainty may underestimate *kse*. |
| *ksr* | COPC loss constant due to surface runoff | $yr^{-1}$ | **Varies**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-1-4. No reference document is cited for this equation; however, using this equation is consistent with U.S. EPA (1998). U.S. EPA (1994a) assumed that all *ksr* values are zero but didn't explain the basis for this assumption.<br><br>Uncertainties associated with this variable (calculated by using the equation in Table B-1-4) include the following:<br>(1) The source of the equation in Table B-1-4 has not been identified.<br>(2) For soluble COPCs, leaching might lead to movement to below $Z_s$, resulting in lower concentrations within the $Z_s$. This uncertainty may overestimate *ksr*.<br>(3) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) compared to other residues. This uncertainty may underestimate *ksr*. |
| *ksl* | COPC loss constant due to leaching | $yr^{-1}$ | **Varies**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-1-5. Using this equation is consistent with U.S. EPA (1998), U.S. EPA (1994b), and NC DEHNR (1997). U.S. EPA (1994a) assumed that *ksl* is zero but didn't explain the basis of this assumption.<br><br>Uncertainties associated with this variable (calculated by using the equation in Table B-1-5) include the following:<br>(1) The source of the equation in Table B-1-5 has not been identified.<br>(2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) compared to 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 | $yr^{-1}$ | **Varies**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-1-6. This equation calculates the COPC loss constant from soil due to volatilization, and was obtained from U.S. EPA (1998). The soil loss constant due to volatilization (*ksv*) is based on gas equilibrium coefficients and gas phase mass transfer. The first order decay constant, *ksv*, is obtained by adapting the Hwang and Falco equation for soil vapor phase diffusion (Hwang and Falco 1986).<br><br>Uncertainties associated with this equation include the following:<br>(1) For soluble COPCs, leaching might lead to movement to below 2 centimeter in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksv*.<br>(2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) compared to other residues. This uncertainty may underestimate *ksv*. |

**REFERENCES AND DISCUSSION**

Hwang S. T. and Falco, J. W. 1986. "Estimation of multimedia exposures related to hazardous waste facilities", In: *Pollutants in a Multimedia Environment.* Yoram Cohen, Ed. Plenum Publishing Corp. New York.

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 and B-1-5. 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 assuming that the loss resulting from erosion (*kse*) is zero because of contaminated soil eroding both onto the site and away from the site.

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.

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.

This document is one of the reference documents for the equations in Tables B-1-4 and B-1-5. 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-1-2**

**COPC SOIL LOSS CONSTANT**
**(SOIL INGESTION EQUATIONS)**

**(Page 4 of 4)**

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

This document is one of the reference documents for the equations for *ksr*, *ksl*, and *ksv*.

**TABLE B-1-3**

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

**(Page 1 of 5)**

**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), we recommend a default value of zero for *kse* 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*, we recommend using the equation presented in this table along with associated uncertainties. You can find additional discussion on determining *kse* in U.S. EPA (1998). Uncertainties associated with this equation include:

(1) For soluble COPCs, leaching might lead to movement below 2 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**

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

| Variable | Description | Units | Value |
|---|---|---|---|
| *kse* | COPC loss constant due to soil erosion | $yr^{-1}$ | **0**<br>Consistent with U.S. EPA (1994), U.S. EPA (1994b), and NC DEHNR (1997), we recommend that the default value assumed for *kse* is zero because contaminated soil erodes both onto the site and away from the site. uncertainty may overestimate *kse*. |
| *0.1* | Units conversion factor | $g\text{-}kg/cm^2\text{-}m^2$ | |
| $X_e$ | Unit soil loss | $kg/m^2\text{-}yr$ | **Varies**<br>This variable is site-specific and is calculated by using the equation in Table B-4-13.<br><br>The following uncertainty is associated with this variable:<br>All of the equation variables are site-specific. Using 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, we expect $X_e$ estimates to vary over a range of less than two orders of magnitude. |

**TABLE B-1-3**

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

**(Page 2 of 5)**

| Variable | Description | Units | Value |
|---|---|---|---|
| *SD* | Sediment delivery ratio | unitless | **Varies**<br>This value is site-specific, and is calculated by using the equation in Table B-4-14.<br><br>Uncertainties associated with this variable include the following:<br>(1) The recommended default values for the empirical intercept coefficient, *a*, are average values based on studies of sediment yields from various watersheds. Therefore, those default values may not accurately represent site-specific watershed conditions. As a result, using these default values may under- or overestimate *SD*.<br>(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, using the default value may under- or overestimate *SD*. |
| *ER* | Soil enrichment ratio | unitless | **Inorganics: 1**<br>**Organics: 3**<br>COPC enrichment occurs because (1) lighter soil particles erode more quickly 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 1998). In the absence of site-specific data, we recommend a default value of 3 for organic COPCs and 1 for inorganic COPCs. This is consistent with other Agency guidance (1998), 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 1998); 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 1998).<br><br>The following uncertainty is associated with this variable:<br>The default *ER* value may not accurately reflect site-specific conditions; therefore, *kse* may be over- or underestimated to an unknown extent. Using county-specific *ER* values will reduce the extent of any uncertainties. |
| *BD* | Soil bulk density | g soil/cm$^3$ soil | **1.5**<br>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 (1998). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g soil/cm$^3$ soil, based on a mean value for loam soil obtained from Carsel et al. (1988). U.S. EPA (1998) stated that a value of 1.5 would suffice for most uses, if site-specific information was unavailable.<br><br>The following uncertainty is associated with this variable:<br>The recommended *BD* value may not accurately represent site-specific soil conditions. It may under- or overestimate site-specific soil conditions to an unknown degree. |

**TABLE B-1-3**

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

**(Page 3 of 5)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $Z_s$ | Soil mixing zone depth | cm | **2 to 20**<br>We recommend the following values for $Z_s$:<br><br>Soil / Depth (cm) / Reference<br>Untilled / 2 / Brzuzy et al. (1995)<br>Tilled / 20 / U.S. EPA (1998)<br><br>U.S. EPA (1992) recommended values of 1 cm (for untilled) and 20cm (for tilled soil). These values are consistent with U.S. EPA (1998), which further states that leaching soluble compounds might lead to movement below a 1-cm depth. A default value of 2 cm for untilled soil mixing depth is based on a study that profiled dioxin measurements within soil (Brzuzy et al. 1995). A default value of 20 cm for tilled soil mixing depth is based on U.S. EPA (1998).<br><br>The following uncertainties are associated with this variable:<br>(1) For soluble COPCs, leaching might lead to movement to below $Z_s$, resulting in lower concentrations within the $Z_s$. This uncertainty may overestimate *Cs* and $Cs_{tD}$.<br>(2) Deposition to hard surfaces may result in dust residues that have negligible dilution compared to other residues. This uncertainty may underestimate *Cs* and $Cs_{tD}$. |
| $Kd_s$ | Soil-water partition coefficient | ml water/g soil (or $cm^3$ water/g soil) | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail and offer COPC-specific values in Appendix A-2.<br><br>The following uncertainty is associated with this variable:<br>Uncertainties associated with this parameter will be limited if $Kd_s$ values are calculated as described in Appendix A-2. |
| $\theta_{sw}$ | Soil volumetric water content | ml water/$cm^3$ soil | **0.2**<br>This variable is site-specific, and depends on the available water and on soil structure; you can estimate $\theta_{sw}$ as the midpoint between a soil's field capacity and wilting point, if you can identify a representative watershed soil. However, we recommend using 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 (1998) (no source or reference is provided for this range) and is consistent with U.S. EPA (1994b).<br><br>The following uncertainty is associated with this variable:<br>The default $\theta_{sw}$ 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-1-3**

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

**(Page 4 of 5)**

**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 (1998) 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.

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 assuming that the loss resulting from erosion (*kse*) is zero because contaminated soil erodes both onto the site and away from the site.

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.

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.

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 et al. (1988), and (2) a default soil volumetric water content, $\theta_{sw}$, value of 0.2 ml water/$cm^3$ soil.

**TABLE B-1-3**

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

**(Page 5 of 5)**

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

This document is the source of a range of COPC enrichment ratio, *ER*, values. The recommended range, 1 to 5, was 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 quickly 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 range of soil volumetric water content ($\theta_{sw}$) 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
- The equations in Tables B-1-3 and B-1-5.

**TABLE B-1-4**

**COPC LOSS CONSTANT DUE TO RUNOFF**
**(SOIL INGESTION EQUATIONS)**

**(Page 1 of 4)**

**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 2 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**<br>This variable is site-specific. According to U.S. EPA (1998), U.S. EPA (1994b), and NC DEHNR (1997), you can estimate *RO* by using the *Water Atlas of the United States* (Geraghty et al. 1973). According to NC DEHNR (1997), you can also use 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.<br><br>The following uncertainty is associated with this variable:<br>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, *ksr* 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 |
|---|---|---|---|
| $\theta_{sw}$ | Soil volumetric water content | ml water/cm$^3$ soil | **0.2**<br>This variable is site-specific, and depends on the available water and on soil structure; you can estimate $\theta_{sw}$ as the midpoint between a soil's field capacity and wilting point, if you can identify a representative watershed soil. We recommend using 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 (1998) (no source or reference is provided for this range), and is consistent with U.S. EPA (1994b) and NC DEHNR (1997).<br><br>The following uncertainty is associated with this variable:<br>The default $\theta_{sw}$ value may not accurately reflect site-specific or local conditions; therefore, *ksr* may be under- or overestimated to a small extent, based on the limited range of values. |
| $Z_s$ | Soil mixing zone depth | cm | **2 to 20**<br>We recommend the following values for $Z_s$:<br><br>Soil — Depth (cm) — Reference<br>Untilled — 2 — Brzuzy et al. (1995)<br>Tilled — 20 — U.S. EPA (1998)<br><br>U.S. EPA (1992) recommended values of 1 cm (for untilled) and 20cm (for tilled soil). These values are consistent with U.S. EPA (1998), which further states that leaching soluble compounds might lead to movement below a 1-cm depth. A default value of 2 cm for untilled soil mixing depth is based on a study that profiled dioxin measurements within soil (Brzuzy et al. 1995). A default value of 20 cm for tilled soil mixing depth is based on U.S. EPA (1998).<br><br>The following uncertainties are associated with this variable:<br>(1) For soluble COPCs, leaching might lead to movement to below $Z_s$, resulting in lower concentrations within the $Z_s$. This uncertainty may overestimate *Cs* and $Cs_{tD}$.<br>(2) Deposition to hard surfaces may result in dust residues that have negligible dilution compared to other residues. This uncertainty may underestimate *Cs* and $Cs_{tD}$. |
| $Kd_s$ | Soil-water partition coefficient | ml water/g soil (or cm$^3$ water/g soil) | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail and offer COPC-specific values in Appendix A-2.<br><br>The following uncertainty is associated with this variable:<br>Uncertainties associated with this parameter will be limited if $Kd_s$ values are calculated as described in Appendix A-2. |

**TABLE B-1-4**

**COPC LOSS CONSTANT DUE TO RUNOFF**
**(SOIL INGESTION EQUATIONS)**

**(Page 3 of 4)**

| Variable | Description | Units | Value |
|---|---|---|---|
| *BD* | Soil bulk density | g soil/cm$^3$ soil | **1.5**<br>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 (1998). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g soil/cm$^3$ soil, based on a mean value for loam soil obtained from Carsel et al. (1988). U.S. EPA (1998) stated that a value of 1.5 would suffice for most uses, if site-specific information was unavailable.<br><br>The following uncertainty is associated with this variable:<br>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 (1998), 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 (1998) 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.

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

- Estimating annual current runoff, *RO* (cm/yr), by using the *Water Atlas of the United States* (Geraghty et al. 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 ($\theta_{sw}$)

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. 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.

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.

This document recommends the following:

- Estimation of average annual runoff, *RO*, by using the *Water Atlas of the United States* (Geraghty et al. 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 et al. (1988)
- Default soil volumetric water content, $\theta_{sw}$, value of 0.2 (ml water/cm$^3$ soil)

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

This document recommends the following:

- A range of soil volumetric water content, $\theta_{sw}$, 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)
- Using the *Water Atlas of the United States* (Geraghty et al. 1973) to calculate average annual runoff, *RO*

**TABLE B-1-5**

**COPC LOSS CONSTANT DUE TO LEACHING**
**(SOIL INGESTION EQUATIONS)**

**(Page 1 of 5)**

**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 2 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) compared to that of other residues. This uncertainty may underestimate *ksl*.
(3) The original source of this equation has not been identified. U.S. EPA (1998) 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**

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

| Variable | Description | Units | Value |
|---|---|---|---|
| *ksl* | COPC loss constant due leaching | $yr^{-1}$ | |
| *P* | Average annual precipitation | cm/yr | **18.06 to 164.19**<br>This variable is site-specific. This range is based on information presented in U.S. EPA (1998), representing data for 69 selected cities (U.S. Bureau of Census 1987; Baes et al. 1984). The 69 selected cities are not identified; however, they appear to be located throughout the continental United States. We recommend using site-specific data.<br><br>The following uncertainty is associated with this variable:<br>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, we expect uncertainty introduced by this variable to be minimal. |

**TABLE B-1-5**

**COPC LOSS CONSTANT DUE TO LEACHING**
**(SOIL INGESTION EQUATIONS)**

**(Page 2 of 5)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $I$ | Average annual irrigation | cm/yr | **0 to 100**<br>This variable is site-specific. This range is based on information presented in U.S. EPA (1998), representing data for 69 selected cities (Baes et al. 1984). The 69 selected cities are not identified; however, they appear to be located throughout the continental United States.<br><br>The following uncertainty is associated with this variable:<br>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**<br>This variable is site-specific. According to U.S. EPA (1998), U.S. EPA (1994b), and NC DEHNR (1997), you can estimate *RO* by using the *Water Atlas of the United States* (Geraghty et al. 1973). According to NC DEHNR (1997), you can also use 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.<br><br>The following uncertainty is associated with this variable:<br>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**<br>This variable is site-specific. This range is based on information presented in U. S. EPA (1998), representing data from 69 selected cities. The 69 selected cities are not identified; however, they appear to be located throughout the continental United States.<br><br>The following uncertainty is associated with this variable:<br>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)**

**(Page 3 of 5)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $\theta_{sw}$ | Soil volumetric water content | ml water/cm$^3$ soil | **0.2**<br>This variable is site-specific, and depends on the available water and on soil structure. You can estimate $\theta_{sw}$ as the midpoint between a soil's field capacity and wilting point, if you can identify a representative watershed soil. We recommend using 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 (1998) (no source or reference is provided for this range) and is consistent with U.S. EPA (1994b) and NC DEHNR (1997).<br><br>The following uncertainty is associated with this variable:<br>The default $\theta_{sw}$ 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 | **2 to 20**<br>We recommend the following values for $Z_s$:<br><br>Soil / Depth (cm) / Reference<br>Untilled / 2 / Brzuzy et al. (1995)<br>Tilled / 20 / U.S. EPA (1998)<br><br>U.S. EPA (1992) recommended values of 1 cm (for untilled) and 20cm (for tilled soil). These values are consistent with U.S. EPA (1998), which further states that leaching soluble compounds might lead to movement below a 1-cm depth. A default value of 2 cm for untilled soil mixing depth is based on a study that profiled dioxin measurements within soil (Brzuzy et al. 1995). A default value of 20 cm for tilled soil mixing depth is based on U.S. EPA (1998).<br><br>The following uncertainties are associated with this variable:<br>(1) For soluble COPCs, leaching might lead to movement to below 2 centimeters in untilled soils, resulting in lower concentrations within the $Z_s$. This uncertainty may overestimate *Cs* and $Cs_{tD}$.<br>(2) Deposition to hard surfaces may result in dust residues that have negligible dilution compared to other residues. This uncertainty may underestimate *Cs* and $Cs_{tD}$. |

**TABLE B-1-5**

**COPC LOSS CONSTANT DUE TO LEACHING**
**(SOIL INGESTION EQUATIONS)**

**(Page 4 of 5)**

| Variable | Description | Units | Value |
|---|---|---|---|
| *BD* | Soil bulk density | g soil/cm$^3$ soil | **1.5**<br>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 (1998). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g soil/cm$^3$ soil, based on a mean value for loam soil obtained from Carsel et al. (1988). U.S. EPA (1998) stated that a value of 1.5 would suffice for most uses, if site-specific information was unavailable.<br><br>The following uncertainty is associated with this variable:<br>The recommended soil bulk density value may not accurately represent site-specific soil conditions. |
| $Kd_s$ | Soil-water partition coefficient | cm$^3$ water/g soil | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail and offer COPC-specific values in Appendix A-2.<br><br>The following uncertainty is associated with this variable:<br>Uncertainties associated with this parameter will be limited if $Kd_s$ values are calculated as described in Appendix A-2. |

**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 (1998), 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 (1998), 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.

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

This document is cited by U.S. EPA (1998) 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.

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 et al. 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, $\theta_{sw}$

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. 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.

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.

This document recommends (1) a default soil volumetric water content, $\theta_{sw}$, value of 0.2 (ml water/$cm^3$ soil), 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 et al. (1988).

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

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.

**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, and comes from *Methodology for Assessing Health Risks Associated with Multiple Exposure Pathways to Combustor Emissions* (U.S. EPA 1998). The soil loss constant due to volatilization (*ksv*) is based on gas equilibrium coefficients and gas phase mass transfer. The first order decay constant, *ksv*, is obtained by adapting the Hwang and Falco equation for soil vapor phase diffusion (Hwang and Falco 1986).

Uncertainties associated with this equation include the following:

(1) For soluble COPCs, leaching might lead to movement to below 2 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) compared to that of other residues. This uncertainty may underestimate *ksv*.

**Equation**

$$ksv = \left[\frac{3.1536 \times 10^{7} \cdot H}{Z_s \cdot Kd_s \cdot R \cdot T_a \cdot BD}\right] \cdot \left(\frac{D_a}{Z_s}\right) \cdot \left[1 - \left(\frac{BD}{\rho_{soil}}\right) - \theta_{sw}\right]$$

| Variable | Definition | Units | Value |
|---|---|---|---|
| *ksv* | COPC loss constant due to volatilization | $yr^{-1}$ | |
| *3.1536 x 10$^{+7}$* | Units conversion factor | s/yr | |
| *H* | Henry's Law constant | atm-$m^3$/mol | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail, and offer COPC-specific values in Appendix A-2.<br><br>The following uncertainty is associated with this variable:<br>Values for this variable, estimated by using the parameters and algorithms in Appendix A-2, may under- or overestimate the actual COPC-specific values. As a result, *ksv* may be under- or overestimated. |

**TABLE B-1-6**

**COPC LOSS CONSTANT DUE TO VOLATILIZATION**
**(SOIL INGESTION EQUATIONS)**

**(Page 2 of 5)**

| Variable | Definition | Units | Value |
|---|---|---|---|
| $Z_s$ | Soil mixing zone depth | cm | **2 to 20**<br>We recommend the following values for $Z_s$:<br><br>Soil — Depth (cm) — Reference<br>Untilled — 2 — Brzuzy et al. (1995)<br>Tilled — 20 — U.S. EPA (1998)<br><br>U.S. EPA (1992) recommended values of 1 cm (for untilled) and 20cm (for tilled soil). These values are consistent with U.S. EPA (1998), which further states that leaching soluble compounds might lead to movement below a 1-cm depth. Additional information on this subject can be obtained from Brzuzy and Hites (1995), which presents soil profiles for dioxin measurements. A default value of 2 cm for soil mixing depth for untilled soils is based on a study that profiled dioxin measurements within soil (Brzuzy et al. 1995). A default value of 20 cm for soil mixing depth for tilled soils is based on U.S. EPA (1998).<br><br>The following uncertainties are associated with this variable:<br>(1) For soluble COPCs, leaching might lead to movement to below 2 centimeter in untilled soils, resulting a greater mixing depth. This uncertainty may overestimate *Cs* and $Cs_{tD}$.<br>(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 $Cs_{tD}$. |
| $Kd_s$ | Soil-water partition coefficient | $cm^3$ water/g soil | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail and offer COPC-specific values in Appendix A-2.<br><br>The following uncertainty is associated with this variable:<br>Uncertainties associated with this parameter will be limited if $Kd_s$ values are calculated as described in Appendix A-2. |
| $R$ | Universal gas constant | atm-$m^3$/mol-K | **$8.205 \times 10^{-5}$**<br>There are no uncertainties associated with this parameter. |

**TABLE B-1-6**

**COPC LOSS CONSTANT DUE TO VOLATILIZATION**
**(SOIL INGESTION EQUATIONS)**

**(Page 3 of 5)**

| Variable | Definition | Units | Value |
|---|---|---|---|
| $T_a$ | Ambient air temperature | K | **298**<br>This variable is site-specific. U.S. EPA (1998) recommends a default ambient air temperature of 298 K.<br><br>The following uncertainty is associated with this variable:<br>To the extent that site-specific or local values for the variable are not available, default values may not accurately represent site-specific conditions. We expect the uncertainty associated with the selection of a single value from within the temperature range at a single location 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**<br>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 (1998). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g soil/cm$^3$ soil, based on a mean value for loam soil obtained from Carsel et al. (1988). U.S. EPA (1998) stated that a value of 1.5 would suffice for most uses, if site-specific information was unavailable.<br><br>The following uncertainty is associated with this variable:<br>The recommended soil bulk density value may not accurately represent site-specific soil conditions. |
| $\rho_{soil}$ | Solids particle density | g/cm$^3$ | **2.7**<br>We recommend using this value, based on Blake and Hartage (1996) and Hillel (1980).<br><br>The solids particle density will vary with location and soil type. |
| $D_a$ | Diffusivity of COPC in air | cm$^2$/s | **Varies**<br>This value is COPC-specific. We discuss this variable in detail, and offer COPC-specific values in Appendix A-2.<br><br>The following uncertainty is associated with this variable:<br>The default $D_a$ values may not accurately represent the behavior of COPCs under site-specific conditions. However, we expect the degree of uncertainty to be minimal. |

**TABLE B-1-6**

**COPC LOSS CONSTANT DUE TO VOLATILIZATION**
**(SOIL INGESTION EQUATIONS)**



| Variable | Definition | Units | Value |
|---|---|---|---|
| $\theta_{sw}$ | Soil volumetric water content | ml water/$cm^3$ soil | **0.2**<br><br>This variable depends on the available water and on soil structure. You can estimate $\theta_{sw}$ as the midpoint between a soil's field capacity and wilting point, if you can identify a representative watershed soil. However, we recommend using 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 (1998) (no source or reference is provided for this range) and is consistent with U.S. EPA (1994b).<br><br>The following uncertainty is associated with this variable:<br>(1) The default $\theta_{sw}$ values may not accurately reflect site-specific or local conditions; therefore, *ksv* may be under- or overestimated to a small extent, based on the limited range of values. |

**REFERENCES AND DISCUSSION**

Blake, GR. and K.H. Hartge. 1996. *Particle Density. Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods.* Second Edition. Arnold Klute, Ed. American Society of Agronomy, Inc. Madison, WI., p. 381.

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.

Hwang S. T. and Falco, J. W. 1986. "Estimation of multimedia exposures related to hazardous waste facilities", In: *Pollutants in a Multimedia Environment.* Yoram Cohen, Ed. Plenum Publishing Corp. New York.

Miller, R.W. and D.T. Gardiner. 1998. In: *Soils in Our Environment.* J.U. Miller, Ed. Prentice Hall. Upper Saddle River, NJ. pp. 80-123.

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.

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.

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 et al. (1988).

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

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
- A range of soil volumetric water content, $\theta_{sw}$

**TABLE B-2-1**

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



**Description**

Use the equations in this table to calculate an average COPC soil concentration resulting from wet and dry deposition of particles and vapors to soil over the exposure duration. We recommend assuming that COPCs are incorporated only to a finite depth (the soil mixing zone depth, $Z_s$). Use the COPC soil concentration averaged over the exposure duration, represented by *Cs*, 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, we recommend using the highest annual average COPC soil concentration occurring during the exposure duration period for noncarcinogenic COPCs. The highest annual average COPC soil concentration would most likely 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) We assume that the time period for deposition of COPCs resulting from hazardous waste combustion is 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 won't 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) A value of zero for $T_1$ doesn't account for exposure that may have occurred from historic operations and emissions from burning hazardous waste. This may underestimate *Cs* and $Cs_{tD}$.
(4) For soluble COPCs, leaching might lead to movement to below the mixing depth, resulting in lower concentrations within the mixing depth. This 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) compared to other residues. This may underestimate *Cs* and $Cs_{tD}$.

**Equation for Carcinogens**

Soil Concentration Averaged Over Exposure Duration

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

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

**TABLE B-2-1**

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



**Equation for Noncarcinogens**

Highest Annual Average Soil Concentration

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

where

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

For mercury modeling

$$Ds_{(Mercury)} = \frac{100 \cdot [0.48 Q_{(Total)}]}{Z_s \cdot BD} \cdot [F_{v_{(Hg^{2+})}} (Dydv + Dywv) + (Dydp + Dywp) \cdot [1 - F_{v_{(Hg^{2+})}}]$$

Use *0.48Q* for total mercury and $F_v = 0.85$ in the mercury modeling equation to calculate *Ds*. Apportion the calculated *Ds* value 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, assume elemental mercury deposition onto soils is negligible or zero. Evaluate elemental mercury for the direct inhalation pathway only (Table B-5-1).

$Ds_{(Hg2+)} = 0.98\ Ds_{(Mercury)}$
$Ds_{(MHg)} = 0.02\ Ds_{(Mercury)}$
$Ds_{(Hg0)} = 0.0$

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, $Hg^{2+}$) and methyl mercury provided in Appendix A-2, 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)**

**(Page 3 of 8)**

| 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**<br>U.S. EPA (1994a) and NC DEHNR (1991) recommend incorporating the use of a deposition term into the *Cs* equation.<br><br>Uncertainties associated with this variable include the following:<br>(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 through modeling. The direction and magnitude of any uncertainties shouldn't be generalized.<br>(2) Based on the narrow recommended ranges, we expect uncertainties associated with *Vdv,* $F_v$, and *BD* to be low.<br>(3) Values for $Z_s$ vary by about one order of magnitude. Uncertainty is greatly reduced if you know whether soils are tilled or untilled. |
| *tD* | Time period over which deposition occurs (time period of combustion) | yr | **30**<br>U.S. EPA (1998) suggests that this period of time can be ≥ 30 years. We recommend using 30 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**<br>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.<br><br>Uncertainty associated with this variable includes the following:<br>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 on applying these values to the site-specific conditions associated with affected facilities. |

**TABLE B-2-1**

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



| Variable | Description | Units | Value |
|---|---|---|---|
| $T_2$ | Length of exposure duration | yr | **6, 30, or 40**<br>We recommend the following reasonable maximum exposure (RME) values for $T_2$:<br><br>Exposure Duration — RME — Reference<br>Child Resident, Farmer Child, Fisher Child — 6 years — U.S. EPA (1997b)<br>Adult Resident and Fisher — 30 years — U.S. EPA (1997b)<br>Farmer — 40 years — U.S. EPA (1994b)<br><br>U.S. EPA (1994c) recommended the following unreferenced values:<br><br>Exposure Duration — Years<br>Subsistence Farmer — 40<br>Adult Resident — 30<br>Subsistence Fisher — 30<br>Child Resident — 9<br><br>Uncertainties associated with this variable include the following:<br>(1) Exposure duration rates are based on historical mobility rates and may not remain constant. This assumption may overestimate or underestimate *Cs* and $Cs_{iD}$.<br>(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 $Cs_{iD}$. |
| $T_1$ | Time period at the beginning of combustion | yr | **0**<br>Consistent with U.S. EPA (1994bc), we recommend a value of 0 for $T_1$.<br><br>The following uncertainty is associated with this variable:<br>A $T_1$ of zero doesn't account for exposure that may have occurred from historical operation or emissions from the combustion of hazardous waste. This may underestimate *Cs* and $Cs_{iD}$. |
| *100* | Units conversion factor | $mg\text{-}cm^2/kg\text{-}cm^2$ | |

**TABLE B-2-1**

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

**(Page 5 of 8)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $Q$ | COPC emission rate | g/s | **Varies**<br>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 | **2 to 20**<br>We recommend the following values for $Z_s$:<br><br>Soil — Depth (cm) — Reference<br>Untilled — 2 — Brzuzy et al. (1995)<br>Tilled — 20 — U.S. EPA (1998)<br><br>U.S. EPA (1992) recommended values of 1 cm (for untilled) and 20cm (for tilled soil). These values are consistent with U.S. EPA (1998), which further states that leaching soluble compounds might lead to movement below a 1-cm depth. A default value of 2 cm for untilled soil mixing depth is based on a study that profiled dioxin measurements within soil (Brzuzy et al. 1995). A default value of 20 cm for tilled soil mixing depth is based on U.S. EPA (1998).<br><br>The following uncertainties are associated with this variable:<br>(1) For soluble COPCs, leaching might lead to movement to below 2 centimeters in untilled soils, resulting a greater mixing depth. This uncertainty may overestimate *Cs* and $Cs_{tD}$.<br>(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**<br>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 (1998). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g soil/cm$^3$ soil, based on a mean value for loam soil obtained from Carsel et al. (1988). U.S. EPA (1998) stated that a value of 1.5 would suffice for most uses, if site-specific information was unavailable.<br><br>The following uncertainty is associated with this variable:<br>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-2-1**

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

**(Page 6 of 8)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $F_v$ | Fraction of COPC air concentration in vapor phase | unitless | **0 to 1**<br>This variable is COPC-specific. We discuss this variable and offer COPC-specific values in Appendix A-2. This range is based on the values presented in Appendix A-2. Values are also presented in U.S. EPA (1994c) and NC DEHNR (1997).<br><br>$F_v$ 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).<br><br>The following uncertainties are associated with this variable:<br>(1) Our $F_v$ calculations assume a default $S_T$ value for background plus local sources, rather than an $S_T$ value for urban sources. If your site is located in an urban area, using 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.<br>(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 $F_v$. |
| *Dydv* | Unitized yearly average dry deposition from vapor phase | s/m$^2$-yr | **Varies**<br>This variable is COPC- and site-specific, and is determined by air modeling (see Chapter 3). Uncertainties associated with this variable are site-specific. |
| *Dywv* | Unitized yearly average wet deposition from vapor phase | s/m$^2$-yr | **Varies**<br>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**<br>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**<br>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)**



**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.

Brzuzy, L.P. and R.A. Hites. 1995. "Estimating the Atmospheric Deposition of Polychlorinated Dibenzo-p-dioxins and Dibenzofurans from Soils." *Environmental Science and Technology*. Volume 29. Pages 2090-2098.

This reference presents soil profiles for dioxin measurements.

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.

Cited by U.S. EPA (1998) for the statement that *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.

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 using (1) a deposition term, *Ds*, and (2) COPC-specific $F_v$ 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 $F_v$ values.

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

The External Review Draft of the MPE document (the final is U.S. EPA 1998) cites this document as the source of values for soil mixing zone depth, $Z_s$, for tilled and untilled soils.

**TABLE B-2-1**

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

**(Page 8 of 8)**


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 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 et al. (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 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.

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 that range from 0.27 to 1 for organic COPCs
- Default soil bulk density value of 1.5 g/cm$^3$, based on a mean for loam soil from Carsel et al. (1988)

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

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

U.S. EPA. 1998. *Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions (MPE)*. Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

**TABLE B-2-2**

**COPC SOIL LOSS CONSTANT**
**(CONSUMPTION OF ABOVEGROUND PRODUCE 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-2-3 through B-2-5 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 loss constant due to biotic and abiotic degradation | $yr^{-1}$ | **Varies**<br>This variable is COPC-specific. Values are available in the COPC tables in Appendix A-2.<br><br>"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.<br><br>The following uncertainty is associated with this variable:<br>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)**

**(Page 2 of 4)**

| Variable | Description | Units | Value |
|---|---|---|---|
| *kse* | COPC loss constant due to soil erosion | $yr^{-1}$ | **0**<br>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), we recommend a default value of zero for *kse* because contaminated soil erodes both onto the site and away from the site.<br><br>Uncertainties associated with this variable include the following:<br>(1) The source of the equation in Table B-2-3 has not been identified.<br>(2) For soluble COPCs, leaching might lead to movement to below 2 centimeters in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *kse*.<br>(3) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) compared to other residues. This uncertainty may underestimate *kse*. |
| *ksr* | COPC loss constant due to surface runoff | $yr^{-1}$ | **Varies**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-2-4. No reference document is cited for this equation. Using this equation is consistent with U.S. EPA (1998) and NC DEHNR (1997). U.S. EPA (1994a) assumes that all *ksr* values are zero but does not explain the basis of this assumption.<br><br>Uncertainties associated with this variable (calculated by using the equation in Table B-2-4) include the following:<br>(1) The source of the equation in Table B-2-4 has not been identified.<br>(2) For soluble COPCs, leaching might lead to movement to below 2 centimeters in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksr*.<br>(3) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) compared to other residues. This uncertainty may underestimate *ksr*. |
| *ksl* | COPC loss constant due to leaching | $yr^{-1}$ | **Varies**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-2-5. Using this equation is consistent with U.S. EPA (1998), U.S. EPA (1994b), and NC DEHNR (1997). U.S. EPA (1994a) states that *ksl* is zero but doesn't explain the basis of this assumption.<br><br>Uncertainties associated with this variable (calculated by using the equation in Table B-2-5) include the following:<br>(1) The source of the equation in Table B-2-5 wasn't identified.<br>(2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) compared to 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 | $yr^{-1}$ | **Varies**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-2-6. This equation calculates the COPC loss constant from soil due to volatilization, and was obtained from U.S. EPA (1998). The soil loss constant due to volatilization (*ksv*) is based on gas equilibrium coefficients and gas phase mass transfer. The first order decay constant, *ksv*, is obtained by adapting the Hwang and Falco equation for soil vapor phase diffusion (Hwang and Falco 1986).<br><br>Uncertainties associated with this equation include the following:<br>(1) For soluble COPCs, leaching might lead to movement to below 2 centimeters in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksv*.<br>(2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) compared to other residues. This uncertainty may underestimate *ksv*. |

**REFERENCES AND DISCUSSION**

Hwang S. T. and Falco, J. W. 1986. "Estimation of multimedia exposures related to hazardous waste facilities", In: *Pollutants in a Multimedia Environment.* Yoram Cohen, Ed. Plenum Publishing Corp. New York.

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 and B-2-5. 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 assuming that the loss resulting from erosion (*kse*) is zero because of contaminated soil eroding both onto the site and away from the site.

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.

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 and B-2-5. This document is also cited as one of the sources that recommend assuming 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-2-2**

**COPC SOIL LOSS CONSTANT**
**(CONSUMPTION OF ABOVEGROUND PRODUCE EQUATIONS)**

**(Page 4 of 4)**

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

This document is one of the reference documents for the equations for *ksr*, *ksl*, and *ksv*.

**TABLE B-2-3**

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

**(Page 1 of 5)**

**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), we recommend a default value of zero for *kse* 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*, we recommend using the equation presented in this table along with associated uncertainties. You can find additional discussion on determining *kse* in U.S. EPA (1998). Uncertainties associated with this equation include:

(1) For soluble COPCs, leaching might lead to movement below 2 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**

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

| Variable | Description | Units | Value |
|---|---|---|---|
| *kse* | COPC loss constant due to soil erosion | $yr^{-1}$ | **0**<br>Consistent with U.S. EPA (1994), U.S. EPA (1994b), and NC DEHNR (1997), we recommend assuming a default value for *kse* of zero because contaminated soil erodes both 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**<br>This variable is site-specific and is calculated by using the equation in Table B-4-13.<br><br>The following uncertainty is associated with this variable:<br>All of the equation variables are site-specific. Using 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**<br>This value is site-specific and is calculated by using the equation in Table B-4-14.<br><br>Uncertainties associated with this variable include the following:<br>(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*.<br>(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**<br>**Organics: 3**<br>COPC enrichment occurs because (1) lighter soil particles erode more quickly 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 1998). In the absence of site-specific data, we recommend a default value of 3 for organic COPCs and 1 for inorganic COPCs. This is consistent with other Agency guidance (1998), 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 1998); 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 1998).<br><br>The following uncertainty is associated with this variable:<br>The default *ER* value may not accurately reflect site-specific conditions; therefore, *kse* may be over- or underestimated to an unknown extent. Using county-specific *ER* values will reduce the extent of any uncertainties. |
| *BD* | Soil bulk density | g soil/cm$^3$ soil | **1.5**<br>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 (1998). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g soil/cm$^3$ soil, based on a mean value for loam soil obtained from Carsel et al. (1988). U.S. EPA (1998) stated that a value of 1.5 would suffice for most uses, if site-specific information was unavailable.<br><br>The following uncertainty is associated with this variable:<br>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-2-3**

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

**(Page 3 of 5)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $Z_s$ | Soil mixing zone depth | cm | **2 to 20**<br>We recommend the following values for $Z_s$:<br><br>Soil — Depth (cm) — Reference<br>Untilled — 2 — Brzuzy et al. (1995)<br>Tilled — 20 — U.S. EPA (1998)<br><br>U.S. EPA (1992) recommended values of 1 cm (for untilled) and 20cm (for tilled soil). These values are consistent with U.S. EPA (1998), which further states that leaching soluble compounds might lead to movement below a 1-cm depth. A default value of 2 cm for untilled soil mixing depth is based on a study that profiled dioxin measurements within soil (Brzuzy et al. 1995). A default value of 20 cm for tilled soil mixing depth is based on U.S. EPA (1998).<br><br>The following uncertainties are associated with this variable:<br>(1) For soluble COPCs, leaching might lead to movement to below 2 centimeters in untilled soils, resulting a greater mixing depth. This uncertainty may overestimate *Cs* and $Cs_{tD}$.<br>(2) Deposition to hard surfaces may result in dust residues that have negligible dilution compared to other residues. This uncertainty may underestimate *Cs* and $Cs_{tD}$. |
| $Kd_s$ | Soil-water partition coefficient | ml water/g soil (or $cm^3$ water/g soil) | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail and offer COPC-specific values in Appendix A-2.<br><br>The following uncertainty is associated with this variable:<br>Uncertainties associated with this parameter will be limited if $Kd_s$ values are calculated as described in Appendix A-2. |
| $\theta_{sw}$ | Soil volumetric water content | ml water/$cm^3$ soil | **0.2**<br>This variable is site-specific, and depends on the available water and on soil structure; you can estimate $\theta_{sw}$ as the midpoint between a soil's field capacity and wilting point, if you can identify a representative watershed soil. However, we recommend using 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 (1998) (no source or reference is provided for this range) and is consistent with U.S. EPA (1994b).<br><br>The following uncertainty is associated with this variable:<br>The default $\theta_{sw}$ 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)

**(Page 4 of 5)**

### 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 (1998) 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.

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 assuming that the loss resulting from erosion (*kse*) is zero because contaminated soil erodes both onto the site and away from the site.

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.

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 et al. (1988), and (2) a default soil volumetric water content, $\theta_{sw}$, value of 0.2 (ml water/cm$^3$ soil), based on U.S. EPA (1993).

**TABLE B-2-3**

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

**(Page 5 of 5)**

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

This document is the source of a range of COPC enrichment ratio, *ER*, values. The recommended range, 1 to 5, was 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 quickly 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 range of soil volumetric water content ($\theta_{sw}$) 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
- The equations in Tables B-1-3 and B-1-5.

**TABLE B-2-4**

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

**(Page 1 of 4)**

**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 2 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**<br>This variable is site-specific. According to U.S. EPA (1998), U.S. EPA (1994b), and NC DEHNR (1997), you can estimate *RO* by using the *Water Atlas of the United States* (Geraghty et al. 1973). According to NC DEHNR (1997), you can also use 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.<br><br>The following uncertainty is associated with this variable:<br>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-2-4**

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

**(Page 2 of 4)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $\theta_{sw}$ | Soil volumetric water content | ml water/cm$^3$ soil | **0.2**<br>This variable is site-specific, and depends on the available water and on soil structure; you can estimate $\theta_{sw}$ as the midpoint between a soil's field capacity and wilting point, if you can identify a representative watershed soil. We recommend using 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 (1998) (no source or reference is provided for this range), and is consistent with U.S. EPA (1994b) and NC DEHNR (1997).<br><br>The following uncertainty is associated with this variable:<br>The default $\theta_{sw}$ value may not accurately reflect site-specific or local conditions; therefore, *ksr* may be under- or overestimated to a small extent, based on the limited range of values. |
| $Z_s$ | Soil mixing zone depth | cm | **2 to 20**<br>We recommend the following values for $Z_s$:<br><br>Soil — Depth (cm) — Reference<br>Untilled — 2 — Brzuzy et al. (1995)<br>Tilled — 20 — U.S. EPA (1998)<br><br>U.S. EPA (1992) recommended values of 1 cm (for untilled) and 20cm (for tilled soil). These values are consistent with U.S. EPA (1998), which further states that leaching soluble compounds might lead to movement below a 1-cm depth. A default value of 2 cm for untilled soil mixing depth is based on a study that profiled dioxin measurements within soil (Brzuzy et al. 1995). A default value of 20 cm for tilled soil mixing depth is based on U.S. EPA (1998).<br><br>The following uncertainties are associated with this variable:<br>(1) For soluble COPCs, leaching might lead to movement to below 2 centimeters in untilled soils, resulting a greater mixing depth. This uncertainty may overestimate *Cs* and $Cs_{tD}$.<br>(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 $Cs_{tD}$. |
| $Kd_s$ | Soil-water partition coefficient | ml water/g soil (or cm$^3$ water/g soil) | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail and offer COPC-specific values in Appendix A-2.<br><br>The following uncertainty is associated with this variable:<br>Uncertainties associated with this parameter will be limited if $Kd_s$ values are calculated as described in Appendix A-2. |

**TABLE B-2-4**

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

**(Page 3 of 4)**

| Variable | Description | Units | Value |
|---|---|---|---|
| *BD* | Soil bulk density | g soil/cm$^3$ soil | **1.5**<br>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 (1998). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g soil/cm$^3$ soil, based on a mean value for loam soil obtained from Carsel et al. (1988). U.S. EPA (1998) stated that a value of 1.5 would suffice for most uses, if site-specific information was unavailable.<br><br>The following uncertainty is associated with this variable:<br>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 (1998), 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 (1998) 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.

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 recommends using 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:

- Estimating annual current runoff, *R*O (cm/yr), by using the *Water Atlas of the United States* (Geraghty et al. 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 ($\theta_{sw}$)

**TABLE B-2-4**

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

**(Page 4 of 4)**


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. 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 et al. 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 et al. (1988)
- Default soil volumetric water content, $\theta_{sw}$, value of 0.2 (ml water/$cm^3$soil), based on U.S. EPA (1993)

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

This document recommends the following:

- A range of soil volumetric water content, $\theta_{sw}$, 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)
- Using the *Water Atlas of the United States* (Geraghty et al. 1973) to calculate average annual runoff, *RO*

**TABLE B-2-5**

**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 2 centimeters 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) compared to other residues. This uncertainty may underestimate *ksl*.
(3) The original source of this equation hasn't been identified. U.S. EPA (1998) 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**

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

| Variable | Description | Units | Value |
|---|---|---|---|
| *ksl* | COPC loss constant due to leaching | $yr^{-1}$ | |
| *P* | Average annual precipitation | cm/yr | **18.06 to 164.19**<br>This variable is site-specific. This range is based on information presented in U.S. EPA (1998), representing data for 69 selected cities (U.S. Bureau of Census 1987; Baes et al. 1984). The 69 selected cities are not identified; however, they appear to be located throughout the continental United States. We recommend using site-specific data.<br><br>The following uncertainty is associated with this variable:<br>(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, we expect uncertainty introduced by this variable to be minimal. |

**TABLE B-2-5**

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

**(Page 2 of 5)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $I$ | Average annual irrigation | cm/yr | **0 to 100**<br>This variable is site-specific. This range is based on information presented in U.S. EPA (1998), representing data for 69 selected cities (Baes et al. 1984). The 69 selected cities are not identified; however, they appear to be located throughout the continental United States.<br><br>The following uncertainty is associated with this variable:<br>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**<br>This variable is site-specific. According to U.S. EPA (1998), U.S. EPA (1994b), and NC DEHNR (1997), you can estimate *RO* by using the *Water Atlas of the United States* (Geraghty et al. 1973). According to NC DEHNR (1997), you can also use 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.<br><br>The following uncertainty is associated with this variable:<br>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**<br>This variable is site-specific. This range is based on information presented in U. S. EPA (1998), representing data from 69 selected cities. The 69 selected cities are not identified; however, they appear to be located throughout the continental United States.<br><br>The following uncertainty is associated with this variable:<br>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-2-5**

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

**(Page 3 of 5)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $\theta_{sw}$ | Soil volumetric water content | (ml water/$cm^3$ soil) | **0.2**<br>This variable is site-specific, and depends on the available water and on soil structure. You can estimate $\theta_{sw}$ as the midpoint between a soil's field capacity and wilting point, if you can identify a representative watershed soil. We recommend using 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 (1998) (no source or reference is provided for this range) and is consistent with U.S. EPA (1994b) and NC DEHNR (1997).<br><br>The following uncertainty is associated with this variable:<br>The default $\theta_{sw}$ 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 | **2 to 20**<br>We recommend the following values for $Z_s$:<br><br>Soil / Depth (cm) / Reference<br>Untilled / 2 / Brzuzy et al. (1995)<br>Tilled / 20 / U.S. EPA (1998)<br><br>U.S. EPA (1992) recommended values of 1 cm (for untilled) and 20cm (for tilled soil). These values are consistent with U.S. EPA (1998), which further states that leaching soluble compounds might lead to movement below a 1-cm depth. A default value of 2 cm for untilled soil mixing depth is based on a study that profiled dioxin measurements within soil (Brzuzy et al. 1995). A default value of 20 cm for tilled soil mixing depth is based on U.S. EPA (1998).<br><br>The following uncertainties are associated with this variable:<br>(1) For soluble COPCs, leaching might lead to movement to below 2 centimeters in untilled soils, resulting a greater mixing depth. This uncertainty may overestimate *Cs* and $Cs_{tD}$.<br>(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 $Cs_{tD}$. |

**TABLE B-2-5**

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

**(Page 4 of 5)**

| Variable | Description | Units | Value |
|---|---|---|---|
| *BD* | Soil bulk density | g soil/cm$^3$ soil | **1.5**<br>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 (1998). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g soil/cm$^3$ soil, based on a mean value for loam soil obtained from Carsel et al. (1988). U.S. EPA (1998) stated that a value of 1.5 would suffice for most uses, if site-specific information was unavailable.<br><br>The following uncertainty is associated with this variable:<br>The recommended *BD* value may not accurately represent site-specific soil conditions. |
| $Kd_s$ | Soil-water partition coefficient | cm$^3$ water/g soil | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail and offer COPC-specific values in Appendix A-2.<br><br>The following uncertainty is associated with this variable:<br>Uncertainties associated with this parameter will be limited if $Kd_s$ values are calculated as described in Appendix A-2. |

**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 (1998), 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 NC DEHNR (1997), U.S. EPA (1994b), and U.S. EPA (1998) 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.

**TABLE B-2-5**

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

**(Page 5 of 5)**


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

This document is cited by U.S. EPA (1998) 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.

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-2-5. 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 et al. 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, $\theta_{sw}$

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. 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 (1998).

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, $\theta_{sw}$, value of 0.2 (ml water/$cm^3$ soil), 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 et al. (1988).

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

This document is one of the reference source documents for the equation in Table B-2-5. 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.

**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, and was obtained from *Methodology for Assessing Health Risks Associated with Multiple Exposure Pathways to Combustor Emissions* (U.S. EPA 1998). The soil loss constant due to volatilization (*ksv*) is based on gas equilibrium coefficients and gas phase mass transfer. The first order decay constant, *ksv*, is obtained by adapting the Hwang and Falco equation for soil vapor phase diffusion (Hwang and Falco 1986).

Uncertainties associated with this equation include the following:

(1) For soluble COPCs, leaching might lead to movement to below 2 centimeters 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) compared to other residues. This uncertainty may underestimate *ksv*.

**Equation**

$$ksv = \left[\frac{3.1536\times10^{7}\cdot H}{Z_s\cdot Kd_s\cdot R\cdot T_a\cdot BD}\right]\cdot\left(\frac{D_a}{Z_s}\right)\cdot\left[1-\left(\frac{BD}{\rho_{soil}}\right)-\theta_{sw}\right]$$

| Variable | Definition | Units | Value |
|---|---|---|---|
| *ksv* | COPC loss constant due to volatilization | $yr^{-1}$ | |
| *3.1536 x 10$^{+07}$* | Units conversion factor | s/yr | |
| *H* | Henry's Law constant | atm-$m^3$/mol | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail, and offer COPC-specific values in Appendix A-2.<br><br>The following uncertainty is associated with this variable:<br>Values for this variable, estimated by using the parameters and algorithms in Appendix A-2, may under- or overestimate the actual COPC-specific values. As a result, *ksv* may be under- or overestimated. |

**TABLE B-2-6**

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

**(Page 2 of 4)**

| Variable | Definition | Units | Value |
|---|---|---|---|
| $Z_s$ | Soil mixing zone depth | cm | **2 to 20**<br>We recommend the following values for $Z_s$:<br><br>Soil — Depth (cm) — Reference<br>Untilled — 2 — Brzuzy et al. (1995)<br>Tilled — 20 — U.S. EPA (1998)<br><br>U.S. EPA (1992) recommended values of 1 cm (for untilled) and 20cm (for tilled soil). These values are consistent with U.S. EPA (1998), which further states that leaching soluble compounds might lead to movement below a 1-cm depth. A default value of 2 cm for untilled soil mixing depth is based on a study that profiled dioxin measurements within soil (Brzuzy et al. 1995). A default value of 20 cm for tilled soil mixing depth is based on U.S. EPA (1998).<br><br>The following uncertainties are associated with this variable:<br>(1) For soluble COPCs, leaching might lead to movement to below 2 centimeters in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *Cs* and $Cs_{tD}$.<br>(2) Deposition to hard surfaces may result in dust residues that have negligible dilution compared to other residues. This uncertainty may underestimate *Cs* and $Cs_{tD}$. |
| $Kd_s$ | Soil-water partition coefficient | $cm^3$ water/g soil | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail and offer COPC-specific values in Appendix A-2.<br><br>The following uncertainty is associated with this variable:<br>Uncertainties associated with this parameter will be limited if $Kd_s$ values are calculated as described in Appendix A-2. |
| $R$ | Universal gas constant | atm-$m^3$/mol-K | **$8.205 \times 10^{-5}$**<br>There are no uncertainties associated with this parameter. |
| $T_a$ | Ambient air temperature | K | **298**<br>This variable is site-specific. U.S. EPA (1990) also recommends an ambient air temperature of 298 K.<br><br>The following uncertainty is associated with this variable:<br>To the extent that site-specific or local values for the variable are not available, default values may not accurately represent site-specific conditions. We expect the uncertainty associated with the selection of a single value from within the temperature range at a single location to be more significant than the uncertainty associated with choosing a single ambient temperature to represent all localities. |

**TABLE B-2-6**

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

**(Page 3 of 4)**

| Variable | Definition | Units | Value |
|---|---|---|---|
| $BD$ | Soil bulk density | g soil/cm$^3$ soil | **1.5**<br>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 (1998). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g soil/cm$^3$ soil, based on a mean value for loam soil obtained from Carsel et al. (1988). U.S. EPA (1998) stated that a value of 1.5 would suffice for most uses, if site-specific information was unavailable.<br><br>The following uncertainty is associated with this variable:<br>The recommended soil bulk density value may not accurately represent site-specific soil conditions. |
| $\rho_{soil}$ | Solids particle density | g/cm$^3$ | **2.7**<br>We recommend using this value, based on Blake and Hartage (1996) and Hillel (1980).<br><br>The solids particle density will vary with location and soil type. |
| $D_a$ | Diffusivity of COPC in air | cm$^2$/s | **Varies**<br>This value is COPC-specific. We discuss this variable in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database.<br><br>The following uncertainty is associated with this variable:<br>The default $D_a$ values may not accurately represent the behavior of COPCs under site-specific conditions. However, we expect the degree of uncertainty to be minimal. |
| $\theta_{sw}$ | Soil volumetric water content | ml/cm$^3$ soil | **0.2**<br>This variable depends on the available water and on soil structure. You can estimate $\theta_{sw}$ as the midpoint between a soil's field capacity and wilting point, if you can identify a representative watershed soil. However, we recommend using 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 (1998) (no source or reference is provided for this range) and is consistent with U.S. EPA (1994b).<br><br>The following uncertainty is associated with this variable:<br>(1) Default $\theta_{sw}$ values may not accurately reflect site-specific or local conditions; therefore, *ksv* may be under- or overestimated to a small extent, based on the limited range of values. |

**TABLE B-2-6**

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



**REFERENCES AND DISCUSSION**

Blake, GR. and K.H. Hartge. 1996. *Particle Density. Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods.* Second Edition. Arnold Klute, Ed. American Society of Agronomy, Inc. Madison, WI., p. 381.

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.

Hwang S. T. and Falco, J. W. 1986. "Estimation of multimedia exposures related to hazardous waste facilities", In: *Pollutants in a Multimedia Environment.* Yoram Cohen, Ed. Plenum Publishing Corp. New York.

Miller, R.W. and D.T. Gardiner. 1998. In: *Soils in Our Environment.* J.U. Miller, Ed. Prentice Hall. Upper Saddle River, NJ. pp. 80-123.

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.

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.

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 et al. (1988).

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

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
- A range of soil volumetric water content, $\theta_{sw}$

**TABLE B-2-7**

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

**(Page 1 of 12)**

**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 recommended equation for calculating *kp* values does not consider chemical degradation processes. Including chemical degradation would decrease the amount of time that a chemical remains on plant surfaces (half-life) and thereby increase *kp* values. *Pd* decreases with increased *kp* values. Reduction of half-life from the assumed 14 days to 2.8 days, for example, would decrease *Pd* about 5-fold.
(3) Calculating 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 don't 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**

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

For mercury modeling

$$Pd_{(Mercury)} = \frac{1000 \cdot 0.48 Q_{(total)} \cdot \left(1 - F_{v_{(Hg^{2+})}}\right) \cdot [Dydp + (Fw \cdot Dywp)] \cdot Rp \cdot [1.0 - e^{(-kp \cdot Tp)}]}{Yp \cdot kp}$$

Use *0.48Q* for total mercury and $F_v = 0.85$ in the mercury modeling equation above to calculate *Pd*. Apportion the calculated *Pd* value 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).

$$Pd_{(Hg2+)} = 0.78\ Pd_{(Mercury)}$$
$$Pd_{(MHG)} = 0.22\ Pd_{(Mercury)}$$

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

**TABLE B-2-7**

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

**(Page 2 of 12)**

| 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**<br>This value is COPC- and site-specific and is determined by air dispersion modeling. See Chapters 2 and 3 for guidance on calculating 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**<br>This variable is COPC-specific. We discuss $F_v$ in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database. This range is based on values presented in Appendix A-2. U.S. EPA (1994b) and NC DEHNR (1997) also present values.<br><br>$F_v$ 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).<br><br>The following uncertainties are associated with this variable:<br>(1) The $F_v$ calculation uses 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, using 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.<br>(2) According to Bidleman (1988), the $F_v$ equation 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 $F_v$.<br>(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 the Agency 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**<br>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)**

**(Page 3 of 12)**

| Variable | Description | Units | Value |
|---|---|---|---|
| *Rp* | Interception fraction of the edible portion of plant | unitless | **0.39**<br>We recommend using this default *Rp* value because it represents the most current information available; specifically, productivity and relative ingestion rates.<br><br>As summarized in Baes et al. (1984), experimental studies of pasture grasses identified a correlation between initial *Rp* values and productivity (standing crop biomass [*Yp*]) (Chamberlain 1970):<br><br>$Rp = 1 - e^{-\gamma \cdot Yp}$<br><br>where<br><br>*Rp* = Interception fraction of the edible portion of plant (unitless)<br>γ = Empirical constant. Chamberlain (1970) presented a range of 2.3 to 3.3; Baes et al. (1984) used 2.88, the midpoint for pasture grasses.<br>*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.<br><br>Baes et al. (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 et al. 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.<br><br>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).<br><br>Uncertainties associated with this variable include the following:<br>(1) The empirical relationship developed by Chamberlain (1970) on the basis of a study of pasture grass may not accurately represent aboveground produce.<br>(2) The empirical constants developed by Baes et al. (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)**

**(Page 4 of 12)**

| Variable | Description | Units | Value |
|---|---|---|---|
| *Fw* | Fraction of COPC wet deposition that adheres to plant surfaces | unitless | **0.2 for anions**<br>**0.6 for cations and most organics**<br>We recommend using the chemical class-specific values of 0.2 for anions and 0.6 for cations and most organics, as 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: We recommend 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-2).<br><br>The values estimated by U.S. EPA (1994b) and U.S. EPA (1995) were based on information presented in Hoffman, et al. (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:<br><br>$r = Rp \cdot Fw$<br><br>The *r* values developed by Hoffman, et al. (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) recommended using the *Fw* value calculated by using the *r* value for insoluble particles to represent organic compounds; however, no rationale for this recommendation was provided.<br><br>Interception values (*r*)—as defined by Hoffman, et al. (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 was not provided.<br><br>Uncertainties associated with this variable include the following:<br>(1) Values of *r* developed experimentally for pasture grass may not accurately represent aboveground produce-specific *r* values.<br>(2) Values of *r* assumed for most organic compounds, based on the behavior of insoluble polystyrene 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**<br>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)**

**(Page 5 of 12)**

| Variable | Description | Units | Value |
|---|---|---|---|
| *kp* | Plant surface loss coefficient | $yr^{-1}$ | **18**<br>We recommend the *kp* value of 18 recommended by U.S. EPA (1998) and U.S. EPA (1994b). The recommended value is the midpoint of a possible range of values (7.44 to 90.36). U.S. EPA (1998) 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 (1998) cites Miller and Hoffman (1983) for the following equation used to estimate *kp*:<br>$kp = (ln\ 2 / t_{1/2}) \cdot 365$ days/yr<br>where<br>$t_{1/2}$ = half-life (days)<br>Miller and Hoffman (1983) report half-life values ranging from 2.8 to 34 days for a variety of COPCs on herbaceous vegetation. These half-life values result in *kp* values of 7.44 to 90.36 ($yr^{-1}$). U.S. EPA (1998) and U.S. EPA (1994b) recommend a *kp* value of 18, based on a generic 14-day half-life, corresponding to physical processes only. You can also calculate site- and compound-specific *kp* values using the equation from Miller and Hoffman (1983).<br>Uncertainties associated with this variable include the following:<br>(1) The recommended equation for calculating *kp* does not consider chemical degradation processes. Adding chemical degradation processes would decrease half-lifes and thereby increase *kp* values; plant concentration decreases as *kp* increases. Using a *kp* value that does not consider chemical degradation processes is protective.<br>(2) The half-life values reported by Miller and Hoffman (1983) may not accurately represent the behavior of compounds on aboveground produce.<br>(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. |

**TABLE B-2-7**

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

**(Page 6 of 12)**

| Variable | Description | Units | Value |
|---|---|---|---|
| *Tp* | Length of plant exposure to deposition per harvest of edible portion of plant | yr | **0.16**<br>We recommend using a *Tp* value of 0.16 years; this is consistent with U.S. EPA (1998), 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:<br>60 days ÷ 365 days/year = 0.16 years<br>The following uncertainty is associated with this variable:<br>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. |

**TABLE B-2-7**

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

**(Page 7 of 12)**

| 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**<br>We recommend 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.<br><br>U.S. EPA (1998) states that the best estimate of *Yp* is productivity. Baes et al. (1984) and Shor et al. (1982) define *Yp* as follows as:<br><br>$$Yp = Yh_i / Ah_i$$<br>where<br>$Yh_i$ = Harvest yield of *i*th crop (kg DW)<br>$Ah_i$ = Area planted to *i*th crop ($m^2$)<br><br>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 et al. 1984).<br><br>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).<br><br>The following uncertainty is associated with this variable:<br>The harvest yield (*Yh*) and area planted (*Ah*) may not reflect site-specific conditions. This may under- or overestimate *Yp*. |

## TABLE B-2-7

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



### 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, $\gamma$, 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 |

Beecher, 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 equation 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*]):

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

where

| | | |
|---|---|---|
| $\gamma$ | = | 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 micro spheres (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-2]), 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-life (days)

The study reports half-life values ranging from 2.8 to 34 days for a variety of COPCs on herbaceous vegetation.

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*:

$$Yp \approx P_i = {}_{Yh}/Ah_i$$

where

$P_i$ = productivity of *i*th crop (kilogram dry weight [kg DW]/square meter [$m^2$])
${}_{Yh}$ = 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 | -- |

Using the empirical relationship developed by Baes et al. (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 et al. (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 et al. (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. 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)— that U.S. EPA (1994b) used to calculate *Rp* and *Yp*.

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 et al. (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.

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 et al. (1982).

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

where

$\gamma$ = Empirical constant; range provided as 2.3 to 3.3

$Yp$ = Standing crop biomass (productivity) (kg DW/$m^2$)

and Shor et al. (1982):

$$Yp = {}_{Yh} / Ah_i$$

where

${}_{Yh}$ = 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.

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

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 et al. (1982).

**TABLE B-2-8**

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



**Description**

This equation calculates the COPC concentration in aboveground produce resulting from direct uptake of vapor phase 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-2). 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, using 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*.

**Equation**

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

For mercury modeling

$$Pv_{(Mercury)} = (0.48Q_{(Mercury)}) \cdot F_{v_{(Hg^{2+})}} \cdot \frac{Cyv \cdot Bv_{ag} \cdot VG_{ag}}{\rho_a}$$

Use *0.48Q* for total mercury and $F_v = 0.85$ in the mercury modeling equation to calculate *Pv*. Apportion the calculated *Pv* value 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.

$$Pv_{(Hg2+)} = 0.78\ Pv_{(Mercury)}$$
$$Pv_{(MHg)} = 0.22\ Pv_{(Mercury)}$$

Evaluate divalent and methyl mercury as individual COPCs. Calculate *Pv* for divalent and methyl mercury using the equations above.

**TABLE B-2-8**

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



| 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**<br>This variable is COPC- and site-specific, and is determined by air dispersion modeling. See Chapters 2 and 3 of the HHRAP for guidance on calculating this variable. Uncertainties associated with this variable are site-specific. |
| $F_v$ | Fraction of COPC air concentration in vapor phase | unitless | **0 to 1**<br>This variable is COPC-specific. We discuss $F_v$ in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database. This range is based on values presented in Appendix A-2. U.S. EPA (1994b) and NC DEHNR (1997) also present values.<br><br>$F_v$ was calculated using an equation presented in Junge (1977) for all organic COPCs, including PCDDs and PCDFs. U.S. EPA (1994c) stated that $F_v = 0$ for all metals (except mercury).<br><br>The following uncertainties are associated with this variable:<br>(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, using 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.<br>(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**<br>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-2-8**

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

**(Page 3 of 5)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $Bv_{ag}$ | COPC air-to-plant biotransfer factor for aboveground produce | unitless<br><br>([mg COPC/g DW plant]/[(mg COPC/g air]) | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database.<br><br>Uncertainty associated with this variable include the following:<br>(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. |
| $VG_{ag}$ | Empirical correction factor for aboveground produce | unitless | **0.01 or 1.0**<br>We recommend using 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.<br><br>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.<br><br>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), recommended 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, et al. (1982).<br><br>Uncertainties associated with this variable include the following:<br>(1) U.S. EPA (1994a) assumed that translocation of compounds deposited on the surface of aboveground vegetation to inner parts of aboveground produce would be insignificant. This may underestimate *P*v.<br>(2) U.S. EPA (1994a) assumed that the density of the skin and the whole vegetable are equal. This may overestimate *Pv*.<br>(3) U.S. EPA (1994a) assumed that the thickness of vegetable skin and broadleaf tree skin are equal. The effect of this assumption on *Pv* is unknown. |
| $\rho_a$ | Density of air | $g/m^3$ | **1200.0**<br>We recommend using 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 $1.2 \times 10^{+3}$.<br><br>U.S. EPA (1994b) and NC DEHNR (1997) recommended this same value but stated that it was calculated at standard conditions (20°C and 1 atmosphere). |

## TABLE B-2-8

## ABOVEGROUND PRODUCE CONCENTRATION DUE TO AIR-TO-PLANT TRANSFER (CONSUMPTION OF ABOVEGROUND PRODUCE 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. *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. 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.

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. No reference or discussion regarding the validity of this assumption was given.

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, et al. (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.

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

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,et al. (1992) algorithm The use of this factor "made predictions [of beef concentrations] come in line with observations."

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*) don't reflect site-specific conditions. This may be especially true for inorganic COPCs for which you could more accurately estimate *Br* by using site-specific *BCFs* rather than *BCF*s presented in Baes et al. (1984). We therefore recommend using 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, calculate aboveground produce concentration due to root uptake 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**<br>This value is COPC-and site-specific and 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<br><br>([mg COPC/kg DW plant]/[mg COPC/ kg soil]) | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database.<br><br>Uncertainties associated with this variable include the following:<br>(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 et al. (1984).<br>(2) We recommend 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 et al. (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. We recommend calculating inorganic-specific *Br* values 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 $K_{ow}$;

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

**TABLE B-2-9**

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



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 et al. (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.

This document recommends using the *BCFs*, *Bv*, and *Br* from Baes et al. (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 et al. (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.

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

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

## TABLE B-2-10

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

**(Page 1 of 5)**

**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*) don't necessarily 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 et al. (1984). Hence, for arsenic, cadmium, selenium, nickel, and zinc, we recommend using 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**<br>This value is COPC-and site-specific and calculated using the equation in Table B-2-1. Uncertainties associated with this variable are site-specific. |

**TABLE B-2-10**

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

**(Page 2 of 5)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $Br_{rootveg}$ | Plant-soil bioconcentration factor for belowground produce | unitless<br><br>([mg COPC/kg plant DW]/[mg COPC/ kg soil]) | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database.<br><br>Uncertainties associated with this variable include the following:<br>(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 et al. (1984).<br>(2) We recommend that you calculate uptake of organic COPCs from soil and the transport of COPCs to belowground produce 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. |

**TABLE B-2-10**

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

**(Page 3 of 5)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $VG_{rootveg}$ | Empirical correction factor for belowground produce | unitless | **0.01 or 1.0**<br>We recommend that you use a $VG_{rootveg}$ value of 0.01 for COPCs with a log $K_{ow}$ greater than 4 and use a $VG_{rootveg}$ value of 1.0 for COPCS with a log $K_{ow}$ less than 4.<br><br>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 isn't likely. In addition, typical preparation techniques, such as washing, peeling, and cooking, will further reduce residues.<br><br>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:<br>$$VG_{rootveg} = \frac{M_{skin}}{M_{vegetable}}$$<br>where<br>$M_{skin}$ = Mass of thin (skin) layer of an below ground vegetable (g)<br>$M_{vegetable}$ = Mass of entire vegetable (g)<br><br>If you assume 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 (1994) recommended a $VG_{rootveg}$ value of 0.01 for lipophilic COPCs.<br><br>The following uncertainty is associated with this variable:<br>U.S. EPA (1994) assumed 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. |
| $Kd_s$ | Soil-water partition coefficient | $cm^3$ water/g soil | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail and offer COPC-specific values in Appendix A-2.<br><br>The following uncertainty is associated with this variable:<br>Uncertainties associated with this parameter will be limited if $Kd_s$ values are calculated as described in Appendix A-2. |

## TABLE B-2-10

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



### 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 et al. (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 et al. (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.

## TABLE B-3-1

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



**Description**

Use the equations in this table to calculate an average COPC soil concentration resulting from wet and dry deposition of particles and vapors to soil over the exposure duration. We recommend assuming that COPCs are incorporated only to a finite depth (the soil mixing zone depth, $Z_s$). Use the COPC soil concentration averaged over the exposure duration, represented by $Cs$, 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, we recommend using the highest annual average COPC soil concentration occurring during the exposure duration period for noncarcinogenic COPCs. The highest annual average COPC soil concentration would most likely 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) We assume that the time period for deposition of COPCs resulting from hazardous waste combustion is 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 won't 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) Using a value of zero for $T_1$ doesn't 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 the mixing depth, resulting in lower concentrations within the 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) compared to other residues. This may underestimate $Cs$ and $Cs_{tD}$.

**Equation for Carcinogens**

Soil Concentration Averaged Over Exposure Duration

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

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

**TABLE B-3-1**

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



**Equation for Noncarcinogens**

Highest Annual Average Soil Concentration

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

where

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

For mercury modeling

$$Ds_{(Mercury)} = \frac{100 \cdot [0.48 Q_{(Total)}]}{Z_s \cdot BD} \cdot [F_{v_{(Hg^{2+})}} (Dydv + Dywv) + (Dydp + Dywp) \cdot [1 - F_{v_{(Hg^{2+})}}]$$

Use *0.48Q* for total mercury and $F_v = 0.85$ in the mercury modeling equation to calculate *Ds*. Apportion the calculated *Ds* value 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, assume elemental mercury deposition onto soils is negligible or zero. Evaluate elemental mercury for the direct inhalation pathway only (Table B-5-1).

$Ds_{(Hg2+)} = 0.98\ Ds_{(Mercury)}$
$Ds_{(Mhg)} = 0.02\ Ds_{(Mercury)}$
$Ds_{(Hg0)} = 0.0$

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, $Hg^{2+}$) and methyl mercury provided in Appendix A-2, and (2) *Ds* ($Hg^{2+}$) and *Ds* (MHg) as calculated above.

**TABLE B-3-1**

**SOIL CONCENTRATION DUE TO DEPOSITION**
**(CONSUMPTION OF ANIMAL PRODUCTS 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**<br>U.S. EPA (1994a) and NC DEHNR (1997) recommended incorporating a deposition term into the *Cs* equation.<br><br>Uncertainties associated with this variable include the following:<br>(1) Five of the variables in the equation for *Ds (Q, Cyv, Dywv*, *Dywp*, and *Dydp*) are COPC- and site-specific. Values for these variables are estimated through modeling. The direction and magnitude of any uncertainties shouldn't be generalized.<br>(2) Based on the narrow recommended ranges, we expect uncertainties associated with *Vdv,* $F_v$, and *BD* to be low.<br>(3) Values for $Z_s$ vary by about one order of magnitude. Uncertainty is greatly reduced if you know whether soils are tilled or untilled. |
| *tD* | Time period over which deposition occurs (time period of combustion) | yr | **30**<br>U.S. EPA (1998) suggests that this period of time can be ≥ 30 years. We recommend using 30 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**<br>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.<br><br>Uncertainty associated with this variable includes the following:<br>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. |

**TABLE B-3-1**

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

**(Page 4 of 8)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $T_2$ | Length of exposure duration | yr | **6, 30, or 40**<br>We recommend reasonable maximum exposure (RME) values for $T_2$:<br><br>Exposure Duration — RME — Reference<br>Child Resident, Farmer Child, Fisher Child — 6 years — U.S. EPA (1997b)<br>Adult Resident and Fisher — 30 years — U.S. EPA (1997b)<br>Farmer — 40 years — U.S. EPA (1994b)<br><br>U.S. EPA (1994c) recommended the following unreferenced values:<br><br>Exposure Duration — Years<br>Subsistence Farmer — 40<br>Adult Resident — 30<br>Subsistence Fisher — 30<br>Child Resident — 9<br><br>Uncertainties associated with this variable include the following:<br>(1) Exposure duration rates are based on historical mobility rates and may not remain constant. This assumption may overestimate or underestimate *Cs* and $Cs_{tD}$.<br>(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**<br>Consistent with U.S. EPA (1994c), we recommend a value of 0 for $T_1$.<br><br>The following uncertainty is associated with this variable:<br>A $T_1$ of zero doesn't account for exposure that may have occurred from historical operation or emissions from burning hazardous waste. This may underestimate *Cs* and $Cs_{tD}$. |
| *100* | Units conversion factor | $mg\text{-}cm^2/kg\text{-}cm^2$ | |

**TABLE B-3-1**

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

**(Page 5 of 8)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $Q$ | COPC emission rate | g/s | **Varies**<br>This variable is COPC- and site-specific. See Chapters 2 and 3 of the HHRAP for guidance on calculating this variable. Uncertainties associated with this variable are site-specific. |
| $Z_s$ | Soil mixing zone depth | cm | **2 to 20**<br>We recommend the following values for $Z_s$:<br><br>Soil — Depth (cm) — Reference<br>Untilled — 2 — Brzuzy et al. (1995)<br>Tilled — 20 — U.S. EPA (1998)<br><br>U.S. EPA (1992) recommended values of 1 cm (for untilled) and 20cm (for tilled soil). These values are consistent with U.S. EPA (1998), which further states that leaching soluble compounds might lead to movement below a 1-cm depth. A default value of 2 cm for untilled soil mixing depth is based on a study that profiled dioxin measurements within soil (Brzuzy et al. 1995). A default value of 20 cm for tilled soil mixing depth is based on U.S. EPA (1998).<br><br>The following uncertainties are associated with this variable:<br>(1) For soluble COPCs, leaching might lead to movement to below 2 centimeters in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *Cs* and $Cs_{tD}$.<br>(2) Deposition to hard surfaces may result in dust residues that have negligible dilution compared to other residues. This uncertainty may underestimate *Cs* and $Cs_{tD}$. |
| *BD* | Soil bulk density | g soil/cm$^3$ soil | **1.5**<br>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 (1998). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g soil/cm$^3$ soil, based on a mean value for loam soil obtained from Carsel et al. (1988). U.S. EPA (1998) stated that a value of 1.5 would suffice for most uses, if site-specific information was unavailable.<br><br>The following uncertainty is associated with this variable:<br>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-3-1**

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

**(Page 6 of 8)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $F_v$ | Fraction of COPC air concentration in vapor phase | unitless | **0 to 1**<br>This variable is COPC-specific. We discuss this variable in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database. This range is based on values presented in Appendix A-2. Values are also presented in U.S. EPA (1994b) and NC DEHNR (1997).<br><br>$F_v$ 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).<br><br>The following uncertainties are associated with this variable:<br>(1) It assumes a default $S_T$ value or background plus local sources, rather than an $S_T$ value for urban sources. If your site is located in an urban area, using 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.<br>(2) According to Bidleman (1988), the $F_v$ equation 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 $F_v$. |
| *Dydv* | Unitized yearly average dry deposition from vapor phase | s/m$^2$-yr | **Varies**<br>This variable is COPC- and site-specific, and is determined by air modeling (see Chapter 3). Uncertainties associated with this variable are site-specific. |
| *Dywv* | Unitized yearly average wet deposition from vapor phase | s/m$^2$-yr | **Varies**<br>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**<br>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**<br>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)



### 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.

Brzuzy, L.P. and R.A. Hites. 1995. "Estimating the Atmospheric Deposition of Polychlorinated Dibenzo-p-dioxins and Dibenzofurans from Soils." *Environmental Science and Technology.* Volume 29. Pages 2090-2098.

This reference presents soil profiles for dioxin measurements.

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.

Cited by U.S. EPA (1998) for the statement that *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.

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-3-1. This document also recommends using (1) a deposition term, *Ds*, and (2) COPC-specific $F_v$ 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 $F_v$ values.

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.

The External Review Draft of the MPE document (the final is U.S. EPA 1998) cites this document as the source of values for soil mixing zone depth, $Z_s$, for tilled and untilled soils.

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.

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 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 et al. (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 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.

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 that range from 0.27 to 1 for organic COPCs
- Default soil bulk density value of 1.5 (g soil/cm$^3$ soil), based on a mean for loam soil from Carsel et al. (1988)

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. 1997b. *Exposure Factors Handbook.* Office of Research and Development. EPA/600/P-95/002Fc. August.

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

U.S. EPA. 1998. *Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions (MPE)*. Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

**TABLE B-3-2**

**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-3-5 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**<br>This variable is COPC-specific and should be determined from the COPC tables in Appendix A-2.<br><br>"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.<br><br>The following uncertainty is associated with this variable:<br>COPC-specific values for *ksg* are empirically determined from field studies; no information is available on applying 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**<br>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), we recommend a default value of zero for *kse* because contaminated soil erodes both onto the site and away from the site.<br><br>Uncertainties associated with this variable include the following:<br>(1) The source of the equation in Table B-3-3 has not been identified.<br>(2) For soluble COPCs, leaching might lead to movement to below 2 centimeters in untilled soils, resulting a greater mixing depth. This uncertainty may overestimate *kse*.<br>(3) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) compared to other residues. This uncertainty may underestimate *kse*. |
| *ksr* | COPC loss constant due to surface runoff | $yr^{-1}$ | **Varies**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-3-4. No reference document is cited for this equation; using this equation is consistent with U.S. EPA (1998). U.S. EPA (1994a) assumes that all *ksr* values are zero but does not explain the basis of this assumption.<br><br>Uncertainties associated with this variable (calculated by using the equation in Table B-3-4) include the following:<br>(1) The source of the equation in Table B-3-4 has not been identified.<br>(2) For soluble COPCs, leaching might lead to movement to below 2 centimeters in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksr*.<br>(3) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) compared to other residues. This uncertainty may underestimate *ksr*. |
| *ksl* | COPC loss constant due to leaching | $yr^{-1}$ | **Varies**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-3-5. Using this equation is consistent with U.S. EPA (1998), U.S. EPA (1994b), and NC DEHNR (1997). U.S. EPA (1994a) assumes that *ksl* is zero but does not explain the basis of this assumption.<br><br>Uncertainties associated with this variable (calculated by using the equation in Table B-3-5) include the following:<br>(1) The source of the equation in Table B-3-5 has not been identified.<br>(2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) compared to other residues. This uncertainty may underestimate *ksl*. |

**TABLE B-3-2**

**COPC SOIL LOSS CONSTANT**
**(CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)**

**(Page 3 of 4)**

| Variable | Description | Units | Value |
|---|---|---|---|
| *ksv* | COPC loss constant due to volatilization | $yr^{-1}$ | **Varies**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-3-6. This equation calculates the COPC loss constant from soil due to volatilization, and was obtained from U.S. EPA (1998). The soil loss constant due to volatilization (*ksv*) is based on gas equilibrium coefficients and gas phase mass transfer. The first order decay constant, *ksv*, is obtained by adapting the Hwang and Falco equation for soil vapor phase diffusion (Hwang and Falco 1986).<br><br>Uncertainties associated with this equation include the following:<br>(1) For soluble COPCs, leaching might lead to movement to below 2 centimeters in untilled soils, resulting in a greater mixing depth. This uncertainty may overestimate *ksv*.<br>(2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) compared to other residues. This uncertainty may underestimate *ksv*. |

**REFERENCES AND DISCUSSION**


Hwang S. T. and Falco, J. W. 1986. "Estimation of multimedia exposures related to hazardous waste facilities", In: *Pollutants in a Multimedia Environment.* Yoram Cohen, Ed. Plenum Publishing Corp. New York.

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 and B-3-5. 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 assuming that the loss resulting from erosion (*kse*) is zero because of contaminated soil eroding both onto the site and away from the site.

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.

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.

This document is one of the reference documents for the equations in Tables B-3-4 and B-3-5. 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-3-2**

**COPC SOIL LOSS CONSTANT**
**(CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)**

**(Page 4 of 4)**

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December. Environmental Criteria and Assessment Office. ORD. Cincinnati, Ohio.

This document is one of the reference documents for the equations for *ksr*, *ksl*, and *ksv*.

**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), we recommend a default value of zero for *kse* 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*, we recommend using the equation presented in this table along with associated uncertainties. You can find additional discussion on determining *kse* in U.S. EPA (1998). Uncertainties associated with this equation include:

(1) For soluble COPCs, leaching might lead to movement below 2 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**

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

| Variable | Description | Units | Value |
|---|---|---|---|
| *kse* | COPC loss constant due to soil erosion | $yr^{-1}$ | **0**<br>Consistent with U.S. EPA (1994), U.S. EPA (1994b), and NC DEHNR (1997), we recommend that the default value assumed for *kse* is zero because contaminated soil erodes onto the site and away from the site. Uncertainty may overestimate *kse*. |
| *0.1* | Units conversion factor | $g\text{-}kg/cm^2\text{-}m^2$ | |
| $X_e$ | Unit soil loss | $kg/m^2\text{-}yr$ | **Varies**<br>This variable is site-specific and is calculated by using the equation in Table B-4-13.<br><br>The following uncertainty is associated with this variable:<br>All of the equation variables are site-specific. Using 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**<br>This value is site-specific and is calculated by using the equation in Table B-4-14.<br><br>Uncertainties associated with this variable include the following:<br>(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, using these default values may under- or overestimate *SD*.<br>(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, using this default value may under- or overestimate *SD*. |
| *ER* | Soil enrichment ratio | unitless | **Inorganics: 1**<br>**Organics: 3**<br>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 1998). In the absence of site-specific data, we recommend a default value of 3 for organic COPCs and 1 for inorganic COPCs. This is consistent with other U.S. EPA guidance (1998), 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 1998); 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 1998).<br><br>The following uncertainty is associated with this variable:<br>The default *ER* value may not accurately reflect site-specific conditions; therefore, *kse* may be over- or underestimated to an unknown extent. Using county-specific *ER* values will reduce the extent of any uncertainties. |
| *BD* | Soil bulk density | g soil/cm$^3$ soil | **1.5**<br>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 (1998). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g soil/cm$^3$ soil, based on a mean value for loam soil obtained from Carsel et al. (1988). U.S. EPA (1998) stated that a value of 1.5 would suffice for most uses, if site-specific information was unavailable.<br><br>The following uncertainty is associated with this variable:<br>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 | **2 to 20**<br>We recommend the following values for $Z_s$:<br><br>Soil / Depth (cm) / Reference<br>Untilled / 2 / Brzuzy et al. (1995)<br>Tilled / 20 / U.S. EPA (1998)<br><br>U.S. EPA (1992) recommended values of 1 cm (for untilled) and 20cm (for tilled soil). These values are consistent with U.S. EPA (1998), which further states that leaching soluble compounds might lead to movement below a 1-cm depth. A default value of 2 cm for untilled soil mixing depth is based on a study that profiled dioxin measurements within soil (Brzuzy et al. 1995). A default value of 20 cm for tilled soil mixing depth is based on U.S. EPA (1998).<br><br>The following uncertainties are associated with this variable:<br>(1) For soluble COPCs, leaching might lead to movement to below 2 centimeters in untilled soils, resulting a greater mixing depth. This uncertainty may overestimate *Cs* and $Cs_{tD}$.<br>(2) Deposition to hard surfaces may result in dust residues that have negligible dilution compared to other residues. This uncertainty may underestimate *Cs* and $Cs_{tD}$. |
| $Kd_s$ | Soil-water partition coefficient | mL water/g soil (or $cm^3$ water/g soil) | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail and offer COPC-specific values in Appendix A-2.<br><br>The following uncertainty is associated with this variable:<br>Uncertainties associated with this parameter will be limited if $Kd_s$ values are calculated as described in Appendix A-2. |
| $\theta_{sw}$ | Soil volumetric water content | mL water/$cm^3$ soil | **0.2**<br>This variable is site-specific, and depends on the available water and on soil structure; you can estimate $\theta_{sw}$ as the midpoint between a soil's field capacity and wilting point, if you can identify a representative watershed soil. However, we recommend using 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 (1998) (no source or reference is provided for this range) and is consistent with U.S. EPA (1994b).<br><br>The following uncertainty is associated with this variable:<br>The default $\theta_{sw}$ 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-3-3

## COPC LOSS CONSTANT DUE TO SOIL EROSION (CONSUMPTION OF ANIMAL PRODUCTS 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 (1998) 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.

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 assuming that the loss resulting from erosion (*kse*) is zero because contaminated soil erodes both onto the site and away from the site.

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.

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.

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.

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 et al. (1988), and (2) a default soil volumetric water content, $\theta_{sw}$, value of 0.2 (mL water/cm$^3$ soil).

**TABLE B-3-3**

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

**(Page 5 of 5)**

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

This document is the source of a range of COPC enrichment ratio, *ER*, values. The recommended range, 1 to 5, was 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 quickly 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 range of soil volumetric water content ($\theta_{sw}$) 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
- The equations in Tables B-3-3 and B-3-5.

**TABLE B-3-4**

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

**(Page 1 of 4)**

**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 2 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**<br>This variable is site-specific. According to U.S. EPA (1998), U.S. EPA (1994b), and NC DEHNR (1997), you can estimate *RO* by using the *Water Atlas of the United States* (Geraghty et al. 1973). According to NC DEHNR (1997), you can also use 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.<br><br>The following uncertainty is associated with this variable:<br>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, *ksr* may be under- or overestimated to an unknown degree. |

**TABLE B-3-4**

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

**(Page 2 of 4)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $\theta_{sw}$ | Soil volumetric water content | mL water/cm$^3$ soil | **0.2**<br>This variable is depends on the available water and soil structure; you can estimate $\theta_{sw}$ as the midpoint between a soil's field capacity and wilting point, if you can identify a representative watershed soil. We recommend using 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 (1998) (no source or reference is provided for this range), and is consistent with U.S. EPA (1994b) and NC DEHNR (1997).<br><br>The following uncertainty is associated with this variable:<br>The default $\theta_{sw}$ value may not accurately reflect site-specific or local conditions; therefore, *ksr* may be under- or overestimated to a small extent, based on the limited range of values. |
| $Z_s$ | Soil mixing zone depth | cm | **2 to 20**<br>We recommend the following values for $Z_s$:<br><br>Soil — Depth (cm) — Reference<br>Untilled — 2 — Brzuzy et al. (1995)<br>Tilled — 20 — U.S. EPA (1998)<br><br>U.S. EPA (1992) recommended values of 1 cm (for untilled) and 20cm (for tilled soil). These values are consistent with U.S. EPA (1998), which further states that leaching soluble compounds might lead to movement below a 1-cm depth. A default value of 2 cm for untilled soil mixing depth is based on a study that profiled dioxin measurements within soil (Brzuzy et al. 1995). A default value of 20 cm for tilled soil mixing depth is based on U.S. EPA (1998).<br><br>The following uncertainties are associated with this variable:<br>(1) For soluble COPCs, leaching might lead to movement to below 2 centimeters in untilled soils, resulting a greater mixing depth. This uncertainty may overestimate *Cs* and $Cs_{tD}$.<br>(2) Deposition to hard surfaces may result in dust residues that have negligible dilution compared to other residues. This uncertainty may underestimate *Cs* and $Cs_{tD}$. |
| $Kd_s$ | Soil-water partition coefficient | mL water/g soil (or cm$^3$ water/g soil) | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail and offer COPC-specific values in Appendix A-2.<br><br>Uncertainties associated with this parameter will be limited if $Kd_s$ values are calculated as described in Appendix A-2. |

**TABLE B-3-4**

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

**(Page 3 of 4)**

| Variable | Description | Units | Value |
|---|---|---|---|
| *BD* | Soil bulk density | g soil/cm$^3$ soil | **1.5**<br>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 (1998). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g soil/cm$^3$ soil, based on a mean value for loam soil obtained from Carsel et al. (1988). U.S. EPA (1998) stated that a value of 1.5 would suffice for most uses, if site-specific information was unavailable.<br><br>The following uncertainty is associated with this variable:<br>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 (1998), 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 (1998) 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.

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 et al. 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 ($\theta_{sw}$)

**TABLE B-3-4**

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



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. 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.

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.

This document recommends the following:

- Estimation of average annual runoff, *R*O, by using the *Water Atlas of the United States* (Geraghty et al. 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 et al. (1988)
- Default soil volumetric water content, $\theta_{sw}$, value of (0.2 mL water/cm$^3$ soil)

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

This document recommends the following:

- A range of soil volumetric water content, $\theta_{sw}$, 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)
- Using the *Water Atlas of the United States* (Geraghty et al. 1973) to calculate average annual runoff, *RO*

**TABLE B-3-5**

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

**(Page 1 of 5)**

**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 2 centimeters 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) compared to other residues. This uncertainty may underestimate *ksl*.
(3) The original source of this equation has not been identified. U.S. EPA (1998) 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**

$$ksl = \frac{P + I - OR - E_v}{\theta_{sw} \cdot Z_s \cdot [10 + (BD \cdot Kd_s / \theta_{sw})]}$$

| 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**<br>This variable is site-specific. This range is based on information presented in U.S. EPA (1998), representing data for 69 selected cities (U.S. Bureau of Census 1987; Baes et al. 1984). The 69 selected cities are not identified; however, they appear to be located throughout the continental United States. We recommend using site-specific data.<br><br>The following uncertainty is associated with this variable:<br>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, we expect uncertainty introduced by this variable 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**<br>This variable is site-specific. This range is based on information presented in U.S. EPA (1998), representing data for 69 selected cities (Baes et al. 1984). The 69 selected cities are not identified; however, they appear to be located throughout the continental United States.<br><br>The following uncertainty is associated with this variable:<br>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**<br>This variable is site-specific. According to U.S. EPA (1998), U.S. EPA (1994b), and NC DEHNR (1997), you can estimate *RO* by using the *Water Atlas of the United States* (Geraghty et al. 1973). According to NC DEHNR (1997), you can also use 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.<br><br>The following uncertainty is associated with this variable:<br>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**<br>This variable is site-specific. This range is based on information presented in U. S. EPA (1998), representing data from 69 selected cities. The 69 selected cities are not identified; however, they appear to be located throughout the continental United States.<br><br>The following uncertainty is associated with this variable:<br>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)**

**(Page 3 of 5)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $\theta_{sw}$ | Soil volumetric water content | mL water/cm$^3$ soil | **0.2**<br>This variable is site-specific, and depends on the available water and on soil structure. You can estimate $\theta_{sw}$ as the midpoint between a soil's field capacity and wilting point, if you can identify a representative watershed soil. We recommend using 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 (1998) (no source or reference is provided for this range) and is consistent with U.S. EPA (1994b) and NC DEHNR (1997).<br><br>The following uncertainty is associated with this variable:<br>The default $\theta_{sw}$ 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 | **2 to 20**<br>We recommend the following values for $Z_s$:<br><br>Soil — Depth (cm) — Reference<br>Untilled — 2 — Brzuzy et al. (1995)<br>Tilled — 20 — U.S. EPA (1998)<br><br>U.S. EPA (1992) recommended values of 1 cm (for untilled) and 20cm (for tilled soil). These values are consistent with U.S. EPA (1998), which further states that leaching soluble compounds might lead to movement below a 1-cm depth. A default value of 2 cm for untilled soil mixing depth is based on a study that profiled dioxin measurements within soil (Brzuzy et al. 1995). A default value of 20 cm for tilled soil mixing depth is based on U.S. EPA (1998).<br><br>The following uncertainties are associated with this variable:<br>(1) For soluble COPCs, leaching might lead to movement to below 2 centimeters in untilled soils, resulting a greater mixing depth. This uncertainty may overestimate *Cs* and $Cs_{tD}$.<br>(2) Deposition to hard surfaces may result in dust residues that have negligible dilution compared to other residues. This uncertainty may underestimate *Cs* and $Cs_{tD}$. |
| *BD* | Soil bulk density | g soil/cm$^3$ soil | **1.5**<br>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 (1998). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g soil/cm$^3$ soil, based on a mean value for loam soil obtained from Carsel et al. (1988). U.S. EPA (1998) stated that a value of 1.5 would suffice for most uses, if site-specific information was unavailable.<br><br>The following uncertainty is associated with this variable:<br>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**<br>This variable is COPC-specific. We discuss this variable in detail and offer COPC-specific values in Appendix A-2.<br><br>The following uncertainty is associated with this variable:<br>Uncertainties associated with this parameter will be limited if $Kd_s$ values are calculated as described in Appendix A-2. |

**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 (1998), 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 (1998), 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.

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

This document is cited by U.S. EPA (1998) 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.

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 et al. 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, $\theta_{sw}$

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 (1998); 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. 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.

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, $\theta_{sw}$, value of 0.2 (mL water/cm$^3$ soil), 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 et al. (1988).

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

This document is one of the reference source documents for the equation in Table B-3-5. 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.

**TABLE B-3-6**

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



**Description**

This equation calculates the COPC loss constant from soil due to volatilization, and was obtained from *Methodology for Assessing Health Risks Associated with Multiple Exposure Pathways to Combustor Emissions* (U.S. EPA 1998). The soil loss constant due to volatilization (*ksv*) is based on gas equilibrium coefficients and gas phase mass transfer. The first order decay constant, *ksv*, is obtained by adapting the Hwang and Falco equation for soil vapor phase diffusion (Hwang and Falco 1986).

Uncertainties associated with this equation include the following:

(1) For soluble COPCs, leaching might lead to movement to below 2 centimeters 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) compared to other residues. This uncertainty may underestimate *ksv*.

**Equation**

$$ksv = \left[\frac{3.1536\times10^{7}\cdot H}{Z_s\cdot Kd_s\cdot R\cdot T_a\cdot BD}\right]\cdot\left(\frac{D_a}{Z_s}\right)\cdot\left[1-\left(\frac{BD}{\rho_{soil}}\right)-\theta_{sw}\right]$$

| Variable | Definition | Units | Value |
|---|---|---|---|
| *ksv* | COPC loss constant due to volatilization | $yr^{-1}$ | |
| *3.1536 x 10$^{+7}$* | Units conversion factor | s/yr | |
| *H* | Henry's Law constant | atm-$m^3$/mol | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database.<br><br>The following uncertainty is associated with this variable:<br>Values for this variable, estimated using the parameters and algorithms in Appendix A-2, may under- or overestimate the actual COPC-specific values. As a result, *ksv* may be under- or overestimated. |

**TABLE B-3-6**

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



| Variable | Definition | Units | Value |
|---|---|---|---|
| $Z_s$ | Soil mixing zone depth | cm | **2 to 20**<br>We recommend the following values for $Z_s$:<br><br>Soil — Depth (cm) — Reference<br>Untilled — 2 — Brzuzy et al. (1995)<br>Tilled — 20 — U.S. EPA (1998)<br><br>U.S. EPA (1992) recommended values of 1 cm (for untilled) and 20cm (for tilled soil). These values are consistent with U.S. EPA (1998), which further states that leaching soluble compounds might lead to movement below a 1-cm depth. A default value of 2 cm for untilled soil mixing depth is based on a study that profiled dioxin measurements within soil (Brzuzy et al. 1995). A default value of 20 cm for tilled soil mixing depth is based on U.S. EPA (1998).<br><br>The following uncertainties are associated with this variable:<br>(1) For soluble COPCs, leaching might lead to movement to below 2 centimeters in untilled soils, resulting a greater mixing depth. This uncertainty may overestimate *Cs* and $Cs_{tD}$.<br>(2) Deposition to hard surfaces may result in dust residues that have negligible dilution compared to other residues. This uncertainty may underestimate *Cs* and $Cs_{tD}$. |
| $Kd_s$ | Soil-water partition coefficient | $cm^3$ water/g soil | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail and offer COPC-specific values in Appendix A-2.<br><br>The following uncertainty is associated with this variable:<br>Uncertainties associated with this parameter will be limited if $Kd_s$ values are calculated as described in Appendix A-2. |
| $R$ | Universal gas constant | atm-$m^3$/mol-K | **$8.205 \times 10^{-5}$**<br>There are no uncertainties associated with this parameter. |
| $T_a$ | Ambient air temperature | K | **298**<br>This variable is site-specific. U.S. EPA (1998) recommends an ambient air temperature of 298 K.<br><br>The following uncertainty is associated with this variable:<br>To the extent that site-specific or local values for $T_a$ are not available, default values may not accurately represent site-specific conditions. We expect the uncertainty associated with the selection of a single value from within the temperature range at a single location to be more significant than the uncertainty associated with choosing a single ambient temperature to represent all localities. |

**TABLE B-3-6**

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



| Variable | Definition | Units | Value |
|---|---|---|---|
| $BD$ | Soil bulk density | g soil/cm$^3$ soil | **1.5**<br>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 (1998). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g soil/cm$^3$ soil, based on a mean value for loam soil obtained from Carsel et al. (1988). U.S. EPA (1998) stated that a value of 1.5 would suffice for most uses, if site-specific information was unavailable.<br><br>The following uncertainty is associated with this variable:<br>The recommended soil bulk density value may not accurately represent site-specific soil conditions. |
| $\rho_{soil}$ | Solids particle density | g/cm$^3$ | **2.7**<br>We recommend the use of this value, based on Blake and Hartage (1996) and Hillel (1980).<br><br>The solids particle density will vary with location and soil type. |
| $D_a$ | Diffusivity of COPC in air | cm$^2$/s | **Varies**<br>This value is COPC-specific. We discuss this variable in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database.<br><br>The following uncertainty is associated with this variable:<br>The default $D_a$ values may not accurately represent the behavior of COPCs under site-specific conditions. However, we expect the degree of uncertainty to be minimal. |
| $\theta_{sw}$ | Soil volumetric water content | mL/cm$^3$ soil | **0.2**<br>This variable depends on the available water and on soil structure. You can estimate $\theta_{sw}$ as the midpoint between a soil's field capacity and wilting point, if you can identify a representative watershed soil. However, we recommend using 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 (1998) (no source or reference is provided for this range) and is consistent with U.S. EPA (1994b).<br><br>The following uncertainty is associated with this variable:<br>(1) The default $\theta_{sw}$ values may not accurately reflect site-specific or local conditions; therefore, *ksv* may be under- or overestimated to a small extent, based on the limited range of values. |

## TABLE B-3-6

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



### REFERENCES AND DISCUSSION

Blake, GR. and K.H. Hartge. 1996. *Particle Density. Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods.* Second Edition. Arnold Klute, Ed. American Society of Agronomy, Inc. Madison, WI., p. 381.

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.

Hwang S. T. and Falco, J. W. 1986. "Estimation of multimedia exposures related to hazardous waste facilities", In: *Pollutants in a Multimedia Environment.* Yoram Cohen, Ed. Plenum Publishing Corp. New York.

Miller, R.W. and D.T. Gardiner. 1998. In: *Soils in Our Environment.* J.U. Miller, Ed. Prentice Hall. Upper Saddle River, NJ. pp. 80-123.

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.

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.

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 et al. (1988).

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

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
- A range of soil volumetric water content, $\theta_{sw}$

**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) Uncertainties associated with the variables *Q, Dydp*, and *Dywp* are *COPC*- are site-specific.
(2) In calculating the variable *Fw*, values of *r* assumed for most organic compounds—based on the behavior of insoluble polystyrene micro spheres 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 equation for calculating *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**

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

$$Pd_{(Mercury)} = \frac{1000 \cdot 0.48 Q_{(total)} \cdot \left(1 - F_{v_{(Hg^{2+})}}\right) \cdot [Dydp + (Fw \cdot Dywp)] \cdot Rp \cdot [1.0 - e^{(-kp \cdot Tp)}]}{Yp \cdot kp}$$

For mercury modeling

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

$$Pd_{(Hg2+)} = 0.78\ Pd_{(Mercury)}$$
$$Pd_{(Mhg)} = 0.22\ Pd_{(Mercury)}$$

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

**TABLE B-3-7**

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



| Variable | Description | Units | Value |
|---|---|---|---|
| *Pd* | Concentration of COPC in forage and silage due to direct deposition | mg COPC/kg DW | |
| *1000* | Units conversion factor | mg/g | |
| *Q* | COPC-specific emission rate | g/s | **Varies**<br>This value is COPC- and site-specific, and is determined by air dispersion modeling. See Chapters 2 and 3 for guidance on calculating this variable. Uncertainties associated with this variable are site-specific. |
| $F_v$ | Fraction of COPC air concentration in vapor phase | unitless | **0 to 1**<br>This variable is COPC-specific. We discuss $F_v$ in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database. This range is based on values presented in Appendix A-2. U.S. EPA (1994b) and NC DEHNR (1997) also present values.<br><br>$F_v$ 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).<br><br>The following uncertainties are associated with this variable:<br>(1) It 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, using 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.<br>(2) According to Bidleman (1988), the $F_v$ equation 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 $F_v$.<br>(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 the Agency 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**<br>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 |
|---|---|---|---|
| *Fw* | Fraction of COPC wet deposition that adheres to plant surfaces | unitless | **0.2 for anions**<br>**0.6 for cations and most organics**<br>We recommend using the chemical class-specific values of 0.2 for anions and 0.6 for cations and most organics, as 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: We recommend 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-2).<br><br>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:<br><br>$r = Rp \cdot Fw$<br><br>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) recommended using the *Fw* value calculated by using the *r* value for insoluble particles to represent organic compounds; however, no rationale for this recommendation was provided.<br><br>Uncertainties associated with this variable include the following:<br>Values of *r* assumed for most organic compounds, based on the behavior of insoluble polystyrene micro spheres tagged with radionuclides, may not accurately represent the behavior of organic compounds under site-specific conditions. |
| *Dywp* | Unitized yearly average wet deposition from particle phase | $s/m^2$-yr | **Varies**<br>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**<br>**Silage: 0.46**<br>We recommend using these default *Rp* values because they represent the most current information available; specifically, productivity and relative ingestion rates.<br><br>As summarized in Baes et al. (1984), experimental studies of pasture grasses identified a correlation between initial *Rp* values and productivity (standing crop biomass [*Yp*]) (Chamberlain 1970):<br><br>$$Rp = 1 - e^{-\gamma \cdot Yp}$$<br><br>where<br>*Rp* = Interception fraction of the edible portion of plant (unitless)<br>$\gamma$ = Empirical constant. Chamberlain (1970) presents a range of 2.3 to 3.3; Baes et al. (1984) uses 2.88, the midpoint for pasture grasses.<br>*Yp* = Yield or standing crop biomass (productivity) (kg DW/$m^2$)<br><br>Baes et al. (1984) proposed using the same empirical relationship developed by Chamberlain (1970) for other vegetation classes. Class-specific estimates of the empirical constant, $\gamma$, were developed by forcing an exponential regression equation through several points, including average and theoretical maximum estimates of *Rp* and *Yp* (Baes et al. 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.<br><br>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).<br><br>Uncertainties associated with this variable include the following:<br>The empirical constants developed by Baes et al. (1984) to use in the empirical relationship developed by Chamberlain (1970) may not accurately represent site-specific mixes of forage or silage. |

**TABLE B-3-7**

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



| Variable | Description | Units | Value |
|---|---|---|---|
| *kp* | Plant surface loss coefficient | $yr^{-1}$ | **18**<br>This value is site-specific. We recommend the *kp* value of 18 recommended by U.S. EPA (1998) 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 (1998) 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 (1998) cites Miller and Hoffman (1983) for the following equation used to estimate *kp*:<br>$kp = (\ln 2 / t_{1/2}) \cdot 365$ days/year<br>where<br>$t_{1/2}$ = half-life (days)<br>Miller and Hoffman (1983) report half-life values ranging from 2.8 to 34 days for a variety of COPCs on herbaceous vegetation. These half-life values convert to *kp* values of 7.44 to 90.36 $yr^{-1}$. U.S. EPA (1998) and U.S. EPA (1994b) recommend a *kp* value of 18, based on a generic 14-day half-life, corresponding to physical processes only. The 14-day half-life is approximately the midpoint of the range (2.8 to 34 days) estimated by Miller and Hoffman (1983).<br>Uncertainties associated with this variable include the following:<br>(1) the recommended equation for calculating *kp* does not consider chemical degradation processes. Adding chemical degradation processes would decrease half-lives and thereby increase *kp* values; plant concentration decreases as *kp* increases. Therefore, using a *kp* value that does not consider chemical degradation processes is conservative.<br>(2) 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. |

**TABLE B-3-7**

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



| Variable | Description | Units | Value |
|---|---|---|---|
| *Tp* | Length of plant exposure to deposition per harvest of edible portion of plant | yr | **Forage: 0.12**<br>**Silage: 0.16**<br>This variable is site-specific. We recommend the using these default values in the absence of site-specific information. U.S. EPA (1998), 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.<br><br>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:<br><br>$Tp = (60 \text{ days} + 30 \text{ days})/ 2 \div 365 \text{ days/yr} = 0.12 \text{ yr}$<br><br>Use these average periods from Beecher and Travis (1989) when calculating the COPC concentration in cattle forage.<br><br>When calculating the COPC concentration in silage fed to cattle, the average period between successive hay harvests (60 days) is used (Beecher and Travis 1989). *Tp* is calculated as follows:<br><br>$Tp = 60 \text{ days} \div 365 \text{ days/year} = 0.16 \text{ year}$<br><br>The following uncertainty is associated with this variable:<br>Using 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. |

**TABLE B-3-7**

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

**(Page 7 of 10)**

| Variable | Description | Units | Value |
|---|---|---|---|
| *Yp* | Yield or standing crop biomass of the edible portion of the plant | kg DW/$m^2$ | **Forage: 0.24**<br>**Silage: 0.8**<br>This variable is site-specific. We recommend 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 et al. (1984) and Shor et al. (1982) define as follows:<br>$Yp \approx {}_{Yh}/Ah_i$<br>where<br>${}_{Yh}$ = Harvest yield of *i*th crop (kg DW)<br>$Ah_i$ = Area planted to crop *i* ($m^2$)<br>U.S. EPA (1994b) and NC DEHNR (1997) recommended using either previously calculated *Yp* values or the equation presented above to calculate a *Yp* value.<br>We recommend 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 on (1) 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:<br>*Yh* = 1.22 x $10^{+11}$ kg DW; from 1993 U.S. average wet weight *Yh* of 1.35 x $10^{11}$ kg (USDA 1994) and conversion factor of 0.9 (Agricultural Research Service 1994)<br>*Ah* = 2.45 x $10^{+11}$ $m^2$; from 1993 U.S. average for hay (USDA 1994).<br>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. We recommend that a production weighted U.S. average *Yp* of 0.8 be assumed for silage (Shor et al. 1982).<br>The following uncertainty is associated with this variable:<br>The harvest yield (*Yh*) and area planted (*Ah*) may not reflect site-specific conditions. This may under- or overestimate *Yp*. |

## TABLE B-3-7

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

## (Page 8 of 10)

### 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 further discussion in reference section of Table B-2-7) 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.

Beecher, 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.

Cited by Baes et al. (1984) as a source for an empirical correlation between initial *Rp* values and productivity (standing crop biomass [*Yp*])

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.

For discussion, see References and Discussion, Table B-2-7.

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.

For discussion, see References and Discussion, Table B-2-7.

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. 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.

This document is the source of relative ingestion rates.

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

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 under Shor et al. (1982).

**TABLE B-3-8**

**FORAGE AND SILAGE CONCENTRATION DUE TO AIR-TO-PLANT TRANSFER (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)**



**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, using 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

$$Pv_{(Mercury)} = (0.48Q_{(Total)}) \cdot F_{v_{(Hg^{2+})}} \cdot \frac{Cyv \cdot Bv_{forage} \cdot VG_{ag}}{\rho_a}$$

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

$Pv_{(Hg2+)} = 0.78\ Pv_{(Mercury)}$

$Pv_{(Mhg)} = 0.22\ Pv_{(Mercury)}$

| 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**<br>This variable is COPC- and site-specific. See Chapters 2 and 3 for guidance on calculating 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**<br>This variable is COPC-specific. We discuss $F_v$ in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database. This range is based on values presented in Appendix A-2. U.S. EPA (1994b) and NC DEHNR (1997) also present values.<br><br>$F_v$ 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).<br><br>The following uncertainties are associated with this variable:<br>(1) It 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, using 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.<br>(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**<br>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**<br>This variable is COPC-specific. We discuss this variable in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database.<br><br>Uncertainty associated with this variable include the following:<br>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**<br>**Silage: 0.5**<br>This variable is site-specific. In the absence of site-specific information, we recommend using $VG_{ag}$ values of 1.0 for forage and 0.5 for silage.<br><br>U.S. EPA (1994a), U.S. EPA (1994b), and NC DEHNR (1997) recommended 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 was 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.<br><br>U.S. EPA (1994a) and U.S. EPA (1994b) recommended 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."<br><br>U.S. EPA (1994a) and U.S. EPA (1994b) didn't recommend a $VG_{ag}$ value for silage. NC DEHNR (1997) recommended a $VG_{ag}$ factor of 0.5 for bulky silage but didn't present a specific rationale for this recommendation. U.S. EPA (1995) noted 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) recommended assuming a $VG_{ag}$ of 0.5 for silage without rigorous justification.<br><br>The following uncertainty is associated with this variable:<br>The $VG_{ag}$ value of 0.5 for silage is recommended without vigorous justification. Depending on the composition of site-specific silage, the recommended value may under- or overestimate the actual value. |

## TABLE B-3-8

## FORAGE AND SILAGE CONCENTRATION DUE TO AIR-TO-PLANT TRANSFER (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)



| Variable | Description | Units | Value |
|---|---|---|---|
| $\rho_a$ | Density of air | $g/m^3$ | **1200.0**<br>We recommend using 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 $1.2 \times 10^{+3}$.<br><br>U.S. EPA (1998) also recommends this value, but states that is was based on a temperature of 25°C. U.S. EPA (1994b) and NC DEHNR (1997) recommended this same value but stated that it was calculated at standard conditions (20°C and 1 atmosphere). Both documents cited Weast (1981). |

### 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 recommended (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 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, et al. (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.

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.

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

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, et al. (1992) algorithm The use of this factor "made predictions [of beef concentrations] come in line with observations."

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*) don't reflect site-specific conditions. This may especially be true for inorganic COPCs for which *Br* would be more accurately estimated by using site-specific bioconcentration factors rather than bioconcentration factors from Baes et al. (1984). We therefore recommend using 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**<br>This value is COPC and site-specific, and 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 |
|---|---|---|---|
| $Br_{forage}$/ $Br_{grain}$ | Plant-soil bioconcentration factor for forage/silage, or grain | unitless<br><br>[(mg COPC/kg plant DW)/ (mg COPC/kg soil)] | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database.<br><br>Uncertainties associated with this variable include the following:<br>(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 et al. (1984).<br>(2) We recommend that you calculate uptake of organic COPCs from soil, and transport of the COPCs to aboveground plant parts, by using 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 $K_{ows}$, based on paired soil and plant concentration data:

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

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 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 et al. (1984) for calculating the uptake of inorganics into vegetative and nonvegetative growth, respectively.

Although most *BCFs* used in this document came from Baes et al. (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 were 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.

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

This is one of the source documents for the equation in Table B-3-9.

**TABLE B-3-10**

**BEEF CONCENTRATION DUE TO PLANT AND SOIL INGESTION**
**(CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)**



**Description**

This equation first estimates the daily amount of COPCs cattle are exposed to through ingesting 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) Using 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**

$$A_{beef} = \left(\sum \left(F_i \cdot Qp_i \cdot P_i\right) + Qs \cdot Cs \cdot Bs\right) \cdot Ba_{beef} \cdot MF$$

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**<br>This variable is site- and plant type-specific. Plant types for cattle are typically identified as grain, forage, and silage. We recommend using a default value of 1.0 for all plant types when site-specific information is not available. This is consistent with U.S. EPA (1998), U.S. EPA (1994a), U.S. EPA (1994b) and NC DEHNR (1997), which recommend assuming that 100 percent of the plant materials ingested by cattle were grown on soil contaminated by emissions.<br><br>The following uncertainty is associated with this variable:<br>(1) Assuming 100 percent of the plant materials eaten by cattle were grown on soil contaminated by emissions may overestimate $A_{beef}$. |

**TABLE B-3-10**

**BEEF 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: 8.8**<br>**Silage: 2.5**<br>**Grain: 0.47**<br>This variable is site- and plant type-specific. Plant types for cattle are typically identified as grain, forage, and silage. We recommend that you use the following *Qp* values when evaluating cattle raised by beef farmers: forage (8.8), silage (2.5), and grain (0.47). These values are consistent with U.S. EPA (1994c), and NC DEHNR (1997).<br><br>The reference documents cite Boone et al. (1981), NAS (1987), McKone and Ryan (1989), and Rice (1994) as primary references for plant ingestion rates.<br><br>Uncertainties introduced by this variable include the following:<br>(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), and (2) daily ingestion rates of forage (8.8 kg/day) and silage (2.5 kg DW/day), recommended by Boone et al. (1981). However, Boone et al. (1981) recommended an alternative daily grain ingestion rate of 1.9 kg DW/day, about four times higher than the rate we recommend. 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.<br>(2) The recommended daily ingestion rates (total and plant type-specific) may not accurately represent site-specific or local conditions. Therefore, $A_{beef}$ may be under- or overestimated, but to a limited degree. |

**TABLE B-3-10**

**BEEF 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**<br>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 $P_i$.<br><br>Uncertainties introduced by this variable include the following:<br>(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.<br>(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 micro spheres), *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 $P_i$.<br>(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.<br>(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**<br>This variable is site-specific. We recommend using a soil ingestion rate of 0.5 kg/day. This is consistent with NC DEHNR (1997) and U.S. EPA (1994c), which cite USDA (1994), Rice (1994), and NAS (1987).<br><br>Uncertainties introduced by this variable include the following:<br>(1) The recommended soil ingestion rate may not accurately represent site-specific or local conditions. However, we expect any differences between the recommended value and site-specific or local soil ingestion rates to be small. Therefore, we likewise expect any uncertainty introduced to be limited. |
| *Cs* | Average soil concentration over exposure duration | mg COPC/kg soil | **Varies**<br>This variable is COPC- and site-specific, and calculated using the equation in Table B-3-1. Uncertainties are site-specific. |

**TABLE B-3-10**

**BEEF CONCENTRATION DUE TO PLANT AND SOIL INGESTION**
**(CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)**



| Variable | Description | Units | Value |
|---|---|---|---|
| $Bs$ | Soil bioavailability factor | unitless | **1.0**<br>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, then 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.<br><br>Since there is not enough data regarding bioavailability from soil, we recommend 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**<br>This variable is COPC-specific. We discuss this variable and COPC-specific values in Appendix A-2. $Ba_{beef}$ 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.<br><br>Uncertainties introduced by this variable include the following:<br><br>(1) We recommend using the regression equation developed by RTI (2005) to calculate $Ba_{beef}$ values for organic COPCs. Uncertainties listed in RTI (2005) in deriving the regression equation include: 1) the necesssity to extrapolate data to steady state conditions, 2) metabolism may not be accounted for equally for all data points, and 3) there is a +/- 0.5 variability in measured Log Kow values available in the literature. In addition, values calculated by using this regression equation may not accurately represent the behavior of organic COPCs under site-specific conditions. $Ba_{beef}$ and subsequent $A_{beef}$ values may therefore be under- or overestimated to some degree.<br>(2) We recommend calculating $Ba_{beef}$ values for metals be using single COPC-specific uptake factors developed by Baes et al. (1984). These uptake factors may not accurately represent the behavior of inorganic COPCs under site-specific conditions. $Ba_{beef}$ and subsequent $A_{beef}$ values may therefore be under- or overestimated to some degree. |
| $MF$ | Metabolism factor | unitless | **0.01 and 1.0**<br>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. |

## TABLE B-3-10

## BEEF CONCENTRATION DUE TO PLANT AND SOIL INGESTION (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)



### 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 et al. (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 et al. (1981) reports forage, grain, and silage ingestion rates of 8.8, 1.9, and 2.5 kg DW/day, respectively, for 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. McKone and Ryan (1989) report an average total ingestion rate of 12 kg DW/day for the three plant feeds, which is consistent with the total recommended by other guidance documents for cattle (that is, forage, grain, and silage total of 11.8 kg DW/day).

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.

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.

Research Triangle Institute (RTI). 2005. *Methodology for Predicting Cattle Biotransfer Factors.* Prepared for U.S. Environmental Protection Agency (EPA) Office fo Solid Waste. EPA Contract No. 68-W-03-042. August.

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. 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). U.S. EPA (1993) recommended a feed ingestion rate of 20 kg DW/day.

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 et al. (1981), NAS (1987), McKone and Ryan (1989), and Rice (1994)
- A soil ingestion rate for cattle ($\theta_{sw}$) of 0.5 kg/day, based on USDA (1994), Rice (1994), and NAS (1987)

U.S. EPA. 1995a. *Further Issues for Modeling the Indirect Exposure Impacts from Combustor Emissions.* Office of Research and Development. Washington, D.C. January.

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.

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

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.

**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**

$$A_{milk} = \left(\sum \left(F_i \cdot Qp_i \cdot P_i\right) + Qs \cdot Cs \cdot Bs\right) \cdot Ba_{milk} \cdot MF$$

For mercury modeling, calculate milk concentrations due to plant and soil ingestion 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**<br>This variable is site- and plant type-specific. Plant types for cattle are identified as grain, forage, and silage. We recommend using a default value of 1.0 for all plant types. This is consistent with U.S. EPA (1998), U.S. EPA (1994a), U.S. EPA (1994b) and NC DEHNR (1997), which recommend assuming that 100 percent of the plant materials ingested by cattle were grown on soil contaminated by emissions.<br><br>The following uncertainty is associated with this variable:<br>(1) Assuming 100 percent of the plant materials eaten by cattle were grown on soil contaminated by facility emissions 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**<br>**Silage: 4.1**<br>**Grain: 3.0**<br>This variable is site- and plant type-specific. Plant types for cattle are identified as grain, forage, and silage. We recommend that you use the following *Qp* values when evaluating cattle raised by milk farmers: forage (13.2), silage (4.1), and grain (3.0).<br><br>The recommended plant type-specific $Qp_i$ values were calculated as follows.<br>***First***, total dry matter intake (DMI) was estimated as 20 kg DW/day, based on information presented in NAS (1987).<br>***Second***, data from Boone et al. (1981) were used to separate the total DMI into plant type-specific fractions.<br>***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.<br>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 (1993; 1994b; 1995), and NC DEHNR (1997). These reference documents cite Boone et al. (1981), NAS (1987), McKone and Ryan (1989), and Rice (1994) as primary references for plant ingestion rates.<br><br>Uncertainties introduced by this variable include the following:<br>(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 et al. (1981) and McKone and Ryan (1989). Site-specific total DMI values may vary.<br>(2) The plant type-specific fractions calculated from Boone et al. (1981) may not accurately represent site-specific or local plant type-specific fractions. |

**TABLE B-3-11**

**MILK 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**<br>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 $P_i$.<br><br>Uncertainties introduced by this variable include the following:<br>(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.<br>(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 micro spheres), *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 $P_i$.<br>(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.<br>(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 | **0.4**<br>This variable is site-specific. We recommend using a soil ingestion rate of 0.4 kg/day. 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.<br>***First***, a total DMI was estimated as 20 kg DW/day based on information presented in NAS (1987).<br>***Second***, USDA (1994) estimates that *Qs* equals 2 percent of the total DMI.<br>***Finally***, the recommended *Qs* value was calculated as 20 kg DW/day · 0.02 = 0.4 kg DW /day.<br><br>Uncertainties introduced by this variable include:<br>(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 et al. (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.<br>(2) USDA (1994) states that *Qs* equals 2 percent of the total DMI for dairy cattle on a 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. |

**TABLE B-3-11**

**MILK CONCENTRATION DUE TO PLANT AND SOIL INGESTION**
**(CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)**

**(Page 4 of 7)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $Cs$ | Average soil concentration over exposure duration | mg COPC/kg soil | **Varies**<br>This variable is COPC- and site-specific, and calculated using the equation in Table B-3-1. Uncertainties are site-specific. |
| $Bs$ | Soil bioavailability factor | unitless | **1.0**<br>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, then 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.<br><br>Due to limited data regarding bioavailability from soil, we recommend 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*. |
| $Ba_{milk}$ | Biotransfer factor for milk | day/kg FW tissue | **Varies**<br>This variable is COPC-specific. A detailed discussion of this variable and COPC-specific values are presented in Appendix A-2. $Ba_{milk}$ 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.<br><br>Uncertainties introduced by this variable include the following:<br><br>(1) We recommend using the regression equation developed by RTI (2005) to calculate $Ba_{milk}$ values for organic COPCs. Uncertainties listed in RTI (2005) in deriving the regression equation include: 1) the necesssity to extrapolate data to steady state conditions, 2) metabolism may not be accounted for equally for all data points, and 3) there is a +/- 0.5 variability in measured Log Kow values available in the literature. In addition, values calculated by using this regression equation may not accurately represent the behavior of organic COPCs under site-specific conditions. $Ba_{milk}$ and subsequent $A_{milk}$ values may therefore be under- or overestimated to some degree.<br>(2) We recommend calculating $Ba_{milk}$ values for metals be using single COPC-specific uptake factors developed by Baes et al. (1984). These uptake factors may not accurately represent the behavior of inorganic COPCs under site-specific conditions. $Ba_{milk}$ and subsequent $A_{milk}$ values may therefore be under- or overestimated to some degree. |

## TABLE B-3-11

## MILK 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**<br>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 et al. (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.

Beecher, 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 et al. (1981) reports a total forage, grain, and silage ingestion rate of 17 kg DW/day for 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).

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. It reports an average total ingestion rate of 17 kg dry weight/day for the three plant feeds, which is consistent with the total recommended by Boone et al. (1981) for cattle.

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 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 et al. (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 $3.5 \times 10^{-10}$ to 4.8, based on Baes et al. (1984).

Research Triangle Institute (RTI). 2005. *Methodology for Predicting Cattle Biotransfer Factors.* Prepared for U.S. Environmental Protection Agency (EPA) Office fo Solid Waste. EPA Contract No. 68-W-03-042. August.

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 farms.

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.

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 et al. (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 $3.5 \times 10^{-10}$ to 4.8, based on Baes et al. (1984)

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 et al. (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. 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.

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

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.

## TABLE B-3-12

## 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 uses 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 cattle metabolism of dioxins rather than a sow metabolism, 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**

$$A_{pork} = \left(\sum \left(F_i \cdot Qp_i \cdot P_i\right) + Qs \cdot Cs \cdot Bs\right) \cdot Ba_{pork} \cdot MF$$

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**<br>This variable is site- and plant type-specific; plant types for swine are typically identified as grain and silage. We recommend using a default value of 1.0 for all plant types. This is consistent with U.S. EPA (1998; 1994a; 1994c), and NC DEHNR (1996), which recommend assuming that 100 percent of the plant materials ingested by swine were grown on soil contaminated by emissions.<br><br>The following uncertainty is associated with this variable:<br>Assuming 100 percent of the plant materials ingested by swine were grown on soil contaminated by facility emissions may overestimate $A_{pork}$. |

**TABLE B-3-12**

**PORK 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 each day | kg DW plant/day | **Silage: 1.4**<br>**Grain: 3.3**<br>This variable is site- and plant type-specific; plant types for swine are typically identified as grain and silage. We recommend that you use the following *Qp* values when evaluating swine raised by farmers: 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).<br><br>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, we recommend 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.<br><br>NC DEHNR (1997) and U.S. EPA (1990) don't 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.<br><br>Uncertainties introduced by this variable include the following:<br>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**<br>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 determine $P_i$.<br><br>Uncertainties introduced by this variable include the following:<br>(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.<br>(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 micro spheres), *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 $P_i$.<br>(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.<br>(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**<br>This variable is site-specific. We recommend using the soil ingestion rate of 0.37 kg/day.<br><br>NC DEHNR (1997) recommended 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· 0.08 = 0.37), which is consistent with U.S. EPA (1995).<br><br>The following uncertainty is associated with this variable:<br>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**<br>This variable is COPC- and site-specific, and calculated 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**<br>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, then 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.<br><br>Due to limited data regarding bioavailability from soil, we recommend 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**<br>This variable is COPC-specific. We discuss this variable in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database. $Ba_{pork}$ 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.<br><br>Uncertainties introduced by this variable include the following:<br>(1) We recommend calculating $Ba_{pork}$ values for organic COPCs from $Ba_{beef}$ values, assuming that pork is 23 percent fat and beef is 19 percent fat. Values derived this way might not accurately represent the behavior of organic COPCs under site-specific conditions. $Ba_{pork}$ and consequent $A_{pork}$ estimates may be under- or overestimated to some degree.<br>(2) The sources or method 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. |
| *MF* | Metabolism factor | unitless | **0.01 and 1.0**<br>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. |

## TABLE B-3-12

## PORK CONCENTRATION DUE TO PLANT AND SOIL INGESTION (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)



### 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.

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 ($1.3 \times 10^{-09}$ to 5.8 day/kg wet tissue); however, the sources of or methodology used to estimate, these values are not identified.

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 et al. (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, et al. (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 $6.0 \times 10^{-04}$ (cadmium); 0.0051 (mercury); $6.255 \times 10^{-01}$ (selenium); and $4.0 \times 10^{-04}$ (zinc).

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.

## 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 home grown chickens that have access to soil.

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 an approach similar to that used to calculate concentrations in animal tissue.

(2) Assuming that 10 percent of a chicken's diet is soil may not represent site-specific conditions. Stephens et al. (1995) suggested 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 calculating $Ba_{egg}$ may not accurately represent the behavior of COPCs under site-specific and local conditions. For example, Stephens et al. (1995) noted that chickens raised under field conditions 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 et al. (1995) presented complete experimental results. This study included results from a high-dose group and a low-dose group; results were based on the full exposure period. A brief comparison of the results from Stephens et al. (1992) with those from Stephens et al. (1995) indicates that *BCFs* from the high-dose group are generally higher than *BCFs* from the low-dose group. Therefore, using the currently recommended *BCFs* may underestimate the COPC concentration in eggs, $A_{egg}$.

**Equation**

$$A_{egg} = \left(\sum \left(F_i \cdot Qp_i \cdot P_i\right) + Qs \cdot Cs \cdot Bs\right) \cdot Ba_{egg}$$

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**<br>This variable is site- and plant type-specific. $F_i$ for chickens is estimated for grain feed only. We recommend using a default value of 1.0. This is consistent with U.S. EPA (1998), U.S. EPA (1994a), U.S. EPA (1994b) and NC DEHNR (1997), which recommend assuming that 100 percent of the plant materials ingested were grown on soil contaminated by facility emissions.<br><br>The following uncertainty is associated with this variable:<br>Assuming that 100 percent of the plant material eaten by chickens was grown on soil contaminated by emissions may overestimate $A_{egg}$. |
| $Qp_i$ | Quantity of plant type *i* (grain) ingested by the animal | kg DW plant/day | **0.2**<br>$Qp_i$ for chicken is estimated for grain feed only, as recommended by NC DEHNR (1997).<br><br>Uncertainties associated with this variable include the following:<br>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**<br>This variable is COPC-, site-, and plant type-specific. Calculate values for *Pi* for grain using the equation in Table B-3-9.<br><br>Uncertainties introduced by this variable include the following:<br>(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.<br>(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 *Br's* would be more accurately estimated by using plant uptake response slope factors. |
| *Qs* | Quantity of soil ingested by the animal | kg/day | **0.022**<br>This variable is site-specific. We recommend that the soil ingestion rate of 0.022 kg/day be used. This is consistent with Stephens et al. (1995).<br><br>Uncertainties introduced by this variable include the following:<br>(1) The recommended soil ingestion rate may not accurately represent site-specific or local conditions.<br>(2) Empirical data to support soil ingestion rates of chickens are limited. |
| *Cs* | Average soil concentration over exposure duration | mg COPC/kg soil | **Varies**<br>This variable is COPC- and site-specific, and calculated using the equation in Table B-3-1. Uncertainties are site-specific. |

**TABLE B-3-13**

**COPC CONCENTRATION IN EGGS**
**(CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)**

**(Page 3 of 5)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $Bs$ | Soil bioavailability factor | unitless | **1.0**<br>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.<br><br>Due to limited data regarding bioavailability from soil, we recommend 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**<br>This variable is COPC-specific. We discuss this variable in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database.<br><br>The following uncertainties are associated with this variable:<br>(1) We recommend calculating $Ba_{egg}$ values for organic COPCs other than dioxins and furans 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.<br>(2) The recommended *BCFs* may not accurately represent the behavior of COPCs under site-specific or local conditions. For example, Stephens et al. (1995) noted 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, $A_{egg}$.<br>(3) The recommended *BCFs* are based on incomplete experimental results. Stephens et al. (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 et al. (1992) and those from Stephens et al. (1995) indicates that *BCFs* from the high-dose group are generally higher than *BCFs* from the low-dose group. Therefore, using the currently recommended *BCFs* may underestimate the COPC concentration in eggs, $A_{egg}$. |

## TABLE B-3-13

## COPC CONCENTRATION IN EGGS
## (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)



### 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 et al. (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 et al. (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 et al. (1992) and Stephens et al. (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 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 et al. (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.

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 $Ba_{egg}$ 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.

U.S. EPA. 1997a. *Exposure Factors Handbook.* "Food Ingestion Factors". Volume II. 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-3-14**

**CONCENTRATION IN CHICKEN**
**(CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)**

**(Page 1 of 5)**

**Description**

This equation calculates the COPC concentration ( $A_{chicken}$) in chicken meat due to ingestion of contaminated soil and grain by home grown chickens that have access to soil.

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 farms. Stephens et al. (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 et al. (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 et al. (1992) with those from Stephens et al. (1995) shows that *BCF*s 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**

$$A_{chicken} = \left( \sum \left( F_i \cdot Qp_i \cdot P_i \right) + Qs \cdot Cs \cdot Bs \right) Ba_{chicken}$$

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**<br>This variable is site- and plant type-specific. $F_i$ for chickens is estimated for grain feed only. We recommend using a default value of 1.0. This is consistent with U.S. EPA (1998), U.S. EPA (1994a), U.S. EPA (1994b) and NC DEHNR (1997), which recommend assuming that 100 percent of the plant materials ingested were grown on soil contaminated by facility emissions.<br><br>The following uncertainty is associated with this variable:<br>Assuming that 100 percent of the plant materials eaten by chickens were grown on soil contaminated by facility emissions may overestimate $A_{chicken}$. |

**TABLE B-3-14**

**CONCENTRATION IN CHICKEN**
**(CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)**

**(Page 2 of 5)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $Qp_i$ | Quantity of plant type *i* (grain) ingested by the animal | kg DW plant/day | **0.2**<br>$Qp_i$ for chicken is estimated for grain feed only, as recommended by NC DEHNR (1997) and U.S. EPA (1990).<br><br>Uncertainties associated with this variable include the following:<br>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**<br>This variable is COPC-, site-, and plant type-specific. Values for *Pi* are calculated for grain using the equations in Table B-3-9.<br><br>Uncertainties introduced by this variable include the following:<br>(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.<br>(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 *Br's* would be more accurately estimated by using plant uptake response slope factors. |
| *Qs* | Quantity of soil ingested by the animal | kg/day | **0.022**<br>This variable is site-specific. We recommend using the soil ingestion rate of 0.022 kg/day. This is consistent with Stephens et al. (1995).<br><br>Uncertainties introduced by this variable include the following:<br>(1) The recommended soil ingestion rate may not accurately represent site-specific or local conditions.<br>(2) Empirical data to support soil ingestion rates of chickens are limited. |
| *Cs* | Average soil concentration over exposure duration | mg COPC/kg soil | **Varies**<br>This variable is COPC- and site-specific, and calculated using the equation in Table B-3-1. Uncertainties are site-specific. |
| *Bs* | Soil bioavailability factor | unitless | **1.0**<br>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, then 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.<br><br>Due to limited data regarding bioavailability from soil, we recommend 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*. |

**TABLE B-3-14**

**CONCENTRATION IN CHICKEN**
**(CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)**

**(Page 3 of 5)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $Ba_{chicken}$ | Biotransfer factor for chicken | day/kg FW tissue | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database. $Ba_{chicken}$ 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.<br><br>Uncertainties associated with this variable include the following:<br>(1) We recommend calculating $Ba_{chicken}$ values for organic COPCs other than dioxins and furans by from $Ba_{beef}$ values by assuming that chicken is 15 percent fat and beef is 19 percent fat. Values calculated this way 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.<br>(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) assumes 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 $A_{chicken}$ values may be under- or overestimated to some degree.<br>(3) The recommended *BCFs* may not accurately represent the behavior of COPCs under site-specific or local conditions. For example, Stephens et al. (1995) noted that chickens raised under field conditions, and which probably had more than 10 percent soil in their diet, showed larger apparent *BCFs*. Therefore, using the recommended *BCFs* may underestimate $A_{chicken}$ , to some extent.<br>(4) The recommended *BCFs* are based on incomplete experimental results. Stephens et al. (1995) presented results that are based on the full 178-day exposure period. A comparison of the results from Stephens et al. (1992) to those from Stephens et al. (1995) shows that *BCFs* from the high-dose group are generally higher than *BCFs* from the low-dose group. Therefore, using the currently recommended *BCFs* may underestimate the COPC concentration in chicken, $A_{chicken}$. |

## TABLE B-3-14

## CONCENTRATION IN CHICKEN
## (CONSUMPTION OF ANIMAL PRODUCTS EQUATIONS)

## (Page 4 of 5)

### REFERENCES AND DISCUSSION


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 et al. (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 et al. (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 et al. (1992) and Stephens et al. (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 Bioaccumulation 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 et al. (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.

U.S. EPA. 1997a. *Exposure Factors Handbook.* "Food Ingestion Factors". Volume II. 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-4-1**

**WATERSHED SOIL CONCENTRATION DUE TO DEPOSITION**
**(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)**



**Description**

Use the equations in this table to calculate an average COPC soil concentration resulting from wet and dry deposition of particles and vapors to soil over the exposure duration. We recommend assuming that COPCs are incorporated only to a finite depth (the soil mixing zone depth, $Z_s$). Use the COPC soil concentration averaged over the exposure duration, represented by *Cs*, 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, we recommend using the highest annual average COPC soil concentration occurring during the exposure duration period for noncarcinogenic COPCs. The highest annual average COPC soil concentration would most likely 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) We assume that the time period for deposition of COPCs resulting from hazardous waste combustion is 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 won't 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) Using a value of zero for $T_1$ doesn't 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 the mixing depth, resulting in lower concentrations within the 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) compared to other residues. This may underestimate *Cs* and $Cs_{tD}$.

**Equation for Carcinogens**

Soil Concentration Averaged Over Exposure Duration

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

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

**TABLE B-4-1**

**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

$$Ds = \frac{100 \cdot Q}{Z_s \cdot BD} \cdot [F_v\,(Dytwv) + Dytwp\,(1 - F_v)]$$

For mercury modeling

$$Ds_{(Mercury)} = \frac{100 \cdot [0.48 Q_{(Total)}]}{Z_s \cdot BD} \cdot [F_{v_{(Hg^{2+})}}\,(Dytwv) + Dytwp \cdot [1 - F_{v_{(Hg^{2+})}}]$$

Use *0.48Q* for total mercury and $F_v = 0.85$ in the mercury modeling equation to calculate *Ds*. Apportion the calculated *Ds* value 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, assume elemental mercury deposition onto soils is negligible or zero. Evaluate elemental mercury for the direct inhalation pathway only (Table B-5-1).

$Ds_{(Hg2+)} = 0.98\ Ds_{(Mercury)}$
$Ds_{(Mhg)} = 0.02\ Ds_{(Mercury)}$
$Ds_{(Hg0)} = 0.0$

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, $Hg^{2+}$) and methyl mercury provided in Appendix A-2, and (2) *Ds* ($Hg^{2+}$) and *Ds* (MHg) as calculated above.

**TABLE B-4-1**

**WATERSHED SOIL CONCENTRATION DUE TO DEPOSITION**
**(CONSUMPTION OF DRINKING WATER AND FISH 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**<br>U.S. EPA (1994a) and NC DEHNR (1991) recommended incorporating a deposition term into the *Cs* equation.<br><br>Uncertainties associated with this variable include the following:<br>(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 through modeling. The direction and magnitude of any uncertainties shouldn't be generalized.<br>(2) Based on the narrow recommended ranges, we expect uncertainties associated with *Vdv,* $F_v$, and *BD* to be low.<br>(3) Values for $Z_s$ vary by about one order of magnitude. Uncertainty is greatly reduced if you know whether soils are tilled or untilled. |
| *tD* | Time period over which deposition occurs (time period of combustion) | yr | **30**<br>U.S. EPA (1998) suggests that this period of time can be ≥ 30 years. We recommend using 30 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**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-4-2. The COPC soil loss constant is the sum of all COPC removal processes.<br><br>Uncertainty associated with this variable includes the following:<br>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. |

**TABLE B-4-1**

**WATERSHED SOIL CONCENTRATION DUE TO DEPOSITION**
**(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)**

**(Page 4 of 8)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $T_2$ | Length of exposure duration | yr | **6, 30, or 40**<br>We recommend reasonable maximum exposure (RME) values for $T_2$:<br>Exposure Duration — RME — Reference<br>Child Resident, Farmer Child, Fisher Child — 6 years — U.S. EPA (1997b)<br>Adult Resident and Fisher — 30 years — U.S. EPA (1997b)<br>Farmer — 40 years — U.S. EPA (1994b)<br>U.S. EPA (1994c) recommended the following unreferenced values:<br>Exposure Duration — Years<br>Subsistence Farmer — 40<br>Adult Resident — 30<br>Subsistence Fisher — 30<br>Child Resident — 9<br>Uncertainties associated with this variable include the following:<br>(1) Exposure duration rates are based on historical mobility rates and may not remain constant. This assumption may overestimate or underestimate $Cs$ and $Cs_{tD}$.<br>(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**<br>Consistent with U.S. EPA (1994c), we recommend a value of 0 for $T_1$.<br>The following uncertainty is associated with this variable:<br>A $T_1$ of zero doesn't account for exposure that may have occurred from historical operation or emissions from the combustion of hazardous waste. This may underestimate $Cs$ and $Cs_{tD}$. |
| *100* | Units conversion factor | $mg\text{-}cm^2/kg\text{-}cm^2$ | |

**TABLE B-4-1**

**WATERSHED SOIL CONCENTRATION DUE TO DEPOSITION**
**(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)**

**(Page 5 of 8)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $Q$ | COPC emission rate | g/s | **Varies**<br>This variable is COPC- and site-specific. See Chapters 2 and 3 of the HHRAP for guidance calculating this variable. Uncertainties associated with this variable are site-specific. |
| $Z_s$ | Soil mixing zone depth | cm | **2 to 20**<br>We recommend the following values for $Z_s$:<br><br>Soil — Depth (cm) — Reference<br>Untilled — 2 — Brzuzy et al. (1995)<br>Tilled — 20 — U.S. EPA (1998)<br><br>U.S. EPA (1992) recommended values of 1 cm (for untilled) and 20cm (for tilled soil). These values are consistent with U.S. EPA (1998), which further states that leaching soluble compounds might lead to movement below a 1-cm depth. A default value of 2 cm for untilled soil mixing depth is based on a study that profiled dioxin measurements within soil (Brzuzy et al. 1995). A default value of 20 cm for tilled soil mixing depth is based on U.S. EPA (1998).<br><br>The following uncertainties are associated with this variable:<br>(1) For soluble COPCs, leaching might lead to movement to below $Z_s$, resulting in lower concentrations within the $Z_s$. This uncertainty may overestimate *Cs* and $Cs_{tD}$.<br>(2) Deposition to hard surfaces may result in dust residues that have negligible dilution compared to other residues. This uncertainty may underestimate *Cs* and $Cs_{tD}$. |
| $BD$ | Soil bulk density | g soil/cm$^3$ soil | **1.5**<br>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 (1998). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g soil/cm$^3$ soil, based on a mean value for loam soil obtained from Carsel et al. (1988). U.S. EPA (1998) stated that a value of 1.5 would suffice for most uses, if site-specific information was unavailable.<br><br>The following uncertainty is associated with this variable:<br>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**<br>This variable is COPC-specific. We discuss $F_v$ in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database. The range is based on values presented in Appendix A-2. Values are also presented in U.S. EPA (1994b) and NC DEHNR (1997).<br><br>$F_v$ 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).<br><br>The following uncertainties are associated with this variable:<br>(1) $F_v$ calculations assume 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, using 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.<br>(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 $F_v$. |
| *Dytwv* | Unitized yearly (water body or watershed) average total deposition from vapor phase | s/m$^2$-yr | **Varies**<br>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**<br>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)

## (Page 7 of 8)

### 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.

Brzuzy, L.P. and R.A. Hites. 1995. "Estimating the Atmospheric Deposition of Polychlorinated Dibenzo-p-dioxins and Dibenzofurans from Soils." *Environmental Science and Technology.* Volume 29. Pages 2090-2098.

This reference presents soil profiles for dioxin measurements.

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, New York.

Cited by U.S. EPA (1998) for the statement that *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.

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-4-1. This document also recommends using (1) a deposition term, *Ds*, and (2) COPC-specific $F_v$ 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 $F_v$ values.

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.

The External Review Draft of the MPE document (the final is U.S. EPA 1998) cites this document as the source of values for soil mixing zone depth, $Z_s$, for tilled and untilled soils.

U.S. EPA. 1993. *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.

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 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.

This document is a reference for the equation in Table B-4-1; it recommends using the following 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 et al. (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 $T_2$ values for the 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.

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 that range from 0.27 to 1 for organic COPCs
- Default soil bulk density value of 1.5 (g soil/cm$^3$ soil), based on a mean for loam soil from Carsel et al. (1988)

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

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

U.S. EPA. 1998. *Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions (MPE)*. Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

This document is a reference for recommended values for soil mixing zone depth, $Z_s$, for tilled and untilled soils.

**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-4-5 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**<br>This variable is COPC-specific. Values are available in the COPC tables in Appendix A-2.<br><br>"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.<br><br>The following uncertainty is associated with this variable:<br>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**<br>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), we recommend a default value of 0 for *kse* because contaminated soil erodes both onto the site and away from the site.<br><br>Uncertainties associated with this variable include the following:<br>(1) The source of the equation in Table B-4-3 has not been identified.<br>(2) For soluble COPCs, leaching might lead to movement to below 2 centimeters in untilled soils, resulting in lower concentrations within the $Z_s$. This uncertainty may overestimate *kse*.<br>(3) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) compared to other residues. This uncertainty may underestimate *kse*. |
| *ksr* | COPC loss constant due to surface runoff | $yr^{-1}$ | **Varies**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-4-4. No reference document is cited for this equation; using this equation is consistent with U.S. EPA (1994b) and NC DEHNR (1997). U.S. EPA (1994a) assumes that all *ksr* values are zero but does not explain the basis of this assumption.<br><br>Uncertainties associated with this variable (calculated using Table B-4-4) include the following:<br>(1) The source of Table B-4-4 has not been identified.<br>(2) For soluble COPCs, leaching might lead to movement to below 2 centimeters in untilled soils, resulting in lower concentrations within the $Z_s$. This uncertainty may overestimate *ksr*.<br>(3) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) compared to other residues. This uncertainty may underestimate *ksr*. |
| *ksl* | COPC loss constant due to leaching | $yr^{-1}$ | **Varies**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-4-5. Using this equation is consistent with U.S. EPA (1998), U.S. EPA(1994b), and NC DEHNR (1997). U.S. EPA (1994a) assumes that all *ksl* values are zero but does not explain the basis of this assumption.<br><br>Uncertainties associated with this variable (calculated using Table B-4-5) include the following:<br>(1) The source of the equation in Table B-4-5 has not been identified.<br>(2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in-situ* materials) compared to other residues. This uncertainty may underestimate *ksl*. |

## TABLE B-4-2

## COPC SOIL LOSS CONSTANT
## (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)



| Variable | Description | Units | Value |
|---|---|---|---|
| *ksv* | COPC loss constant due to volatilization | $yr^{-1}$ | **Varies**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-4-6. This equation calculates the COPC loss constant from soil due to volatilization, and was obtained from U.S. EPA (1998). The soil loss constant due to volatilization (*ksv*) is based on gas equilibrium coefficients and gas phase mass transfer. The first order decay constant, *ksv*, is obtained by adapting the Hwang and Falco equation for soil vapor phase diffusion (Hwang and Falco 1986).<br><br>Uncertainties associated with this equation include the following:<br>(1) For soluble COPCs, leaching might lead to movement to below 2 centimeters in untilled soils, resulting in lower concentrations within the $Z_s$. This uncertainty may overestimate *ksv*.<br>(2) Deposition to hard surfaces may result in dust residues that have negligible dilution (as a result of potential mixing with *in situ* materials) compared to other residues. This uncertainty may underestimate *ksv*. |

### REFERENCES AND DISCUSSION

Hwang S. T. and Falco, J. W. 1986. "Estimation of multimedia exposures related to hazardous waste facilities", In: *Pollutants in a Multimedia Environment.* Yoram Cohen, Ed. Plenum Publishing Corp. New York.

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 and B-4-5. 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 assuming that the loss resulting from erosion (*kse*) is zero because of contaminated soil eroding both onto the site and away from the site.

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.

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.

This document is one of the reference documents for Tables B-4-4 and B-4-5. This document is also cited as one of the sources that recommend assuming 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-4-2**

**COPC SOIL LOSS CONSTANT**
**(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)**

**(Page 4 of 4)**

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

This document is one of the reference documents for the equations for *ksr*, *ksl*, and *ksv*.

**TABLE B-4-3**

**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), we recommend a default value of zero for *kse* is zero because of contaminated soil eroding both onto the site and away from the site. In site-specific cases where the permitting authority considers it appropriate to calculate a *kse*, we recommend using the equation presented in this table along with associated uncertainties. You can find additional discussion on determining *kse* in U.S. EPA (1998). 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) compared to other residues. This uncertainty may underestimate *kse*.

**Equation**

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

| Variable | Description | Units | Value |
|---|---|---|---|
| *kse* | COPC loss constant due to soil erosion | $yr^{-1}$ | **0**<br>Consistent with U.S. EPA (1994), U.S. EPA (1994b), and NC DEHNR (1997), we recommend assuming a default value of zero for *kse* because contaminated soil erodes both onto the site and away from the site. Uncertainty may overestimate *kse*. |
| *0.1* | Units conversion factor | $g\text{-}kg/cm^2\text{-}m^2$ | |
| $X_e$ | Unit soil loss | $kg/m^2\text{-}yr$ | **Varies**<br>This variable is site-specific and is calculated by using the equation in Table B-4-13.<br><br>The following uncertainty is associated with this variable:<br>All of the equation variables are site-specific. Using 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-4-3**

**COPC LOSS CONSTANT DUE TO SOIL EROSION**
**(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)**



| Variable | Description | Units | Value |
|---|---|---|---|
| *SD* | Sediment delivery ratio | unitless | **Varies**<br>This value is site-specific and is calculated using the equation in Table B-4-14.<br><br>Uncertainties associated with this variable include the following:<br>(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, using these default values may under- or overestimate *SD*.<br>(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, using the default value may under- or overestimate *SD*. |
| *ER* | Soil enrichment ratio | unitless | **Inorganics: 1**<br>**Organics: 3**<br>COPC enrichment occurs because (1) lighter soil particles erode more quickly 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 1998). In the absence of site-specific data, we recommend a default value of 3 for organic COPCs and 1 for inorganic COPCs. This is consistent with other Agency guidance (U.S. EPA 1998), 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 1998); 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 1998).<br><br>The following uncertainty is associated with this variable:<br>The default *ER* value may not accurately reflect site-specific conditions; therefore, *kse* may be over- or underestimated to an unknown extent. Using county-specific *ER* values will reduce the extent of any uncertainties. |
| *BD* | Soil bulk density | g soil/cm$^3$ soil | **1.5**<br>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 (1998). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g soil/cm$^3$ soil, based on a mean value for loam soil obtained from Carsel et al. (1988). U.S. EPA (1998) stated that a value of 1.5 would suffice for most uses, if site-specific information was unavailable.<br><br>The following uncertainty is associated with this variable:<br>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)**

**(Page 3 of 5)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $Z_s$ | Soil mixing zone depth | cm | **2 to 20**<br>We recommend the following values for $Z_s$:<br><br>Soil / Depth (cm) / Reference<br>Untilled / 2 / Brzuzy et al. (1995)<br>Tilled / 20 / U.S. EPA (1998)<br><br>U.S. EPA (1992) recommended values of 1 cm (for untilled) and 20cm (for tilled soil). These values are consistent with U.S. EPA (1998), which further states that leaching soluble compounds might lead to movement below a 1-cm depth. A default value of 2 cm for untilled soil mixing depth is based on a study that profiled dioxin measurements within soil (Brzuzy et al. 1995). A default value of 20 cm for tilled soil mixing depth is based on U.S. EPA (1998).<br><br>The following uncertainties are associated with this variable:<br>(1) For soluble COPCs, leaching might lead to movement to below 2 centimeters in untilled soils, resulting a greater mixing depth. This uncertainty may overestimate *Cs* and $Cs_{tD}$.<br>(2) Deposition to hard surfaces may result in dust residues that have negligible dilution compared to of other residues. This uncertainty may underestimate *Cs* and $Cs_{tD}$. |
| $Kd_s$ | Soil-water partition coefficient | mL water/g soil (or $cm^3$ water/g soil) | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail and offer COPC-specific values in Appendix A-2.<br><br>The following uncertainty is associated with this variable:<br>Uncertainties associated with this parameter will be limited if $Kd_s$ values are calculated as described in Appendix A-2. |
| $\theta_{sw}$ | Soil volumetric water content | mL water/$cm^3$ soil | **0.2**<br>This variable is site-specific, and depends on the available water and on soil structure; $\theta_{sw}$ can be estimated as the midpoint between a soil's field capacity and wilting point, if a representative watershed soil can be identified. However, we recommend 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).<br><br>The following uncertainty is associated with this variable:<br>The default $\theta_{sw}$ 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-4-3

## COPC LOSS CONSTANT DUE TO SOIL EROSION (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

## (Page 4 of 5)

### 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 (1998) 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.

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 assuming that the loss resulting from erosion (*kse*) is zero because contaminated soil erodes both onto the site and away from the site.

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.

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.

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.

This document recommends (1) a default *BD* value of 1.5 (g soil/cm$^3$ soil), based on a mean value for loam soil that is taken from Carsel et al. (1988), and (2) a default $\theta_{sw}$, value of 0.2 (mL water/cm$^3$ soil).

**TABLE B-4-3**

**COPC LOSS CONSTANT DUE TO SOIL EROSION**
**(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)**

**(Page 5 of 5)**

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

This document is the source of a range of COPC enrichment ratio, *ER*, values. The recommended range, 1 to 5, was 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 quickly 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 range of $\theta_{sw}$ 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 $Z_s$, for tilled and untilled soil
- The equations in Tables B-1-3 and B-1-5.

**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 2 centimeters 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 compared to 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**<br>This variable is site-specific. According to U.S. EPA (1998), U.S. EPA (1994b), and NC DEHNR (1997), you can estimate *RO* by using the *Water Atlas of the United States* (Geraghty et al. 1973). According to NC DEHNR (1997), you can also use 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.<br><br>The following uncertainty is associated with this variable:<br>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, *ksr* may be under- or overestimated to an unknown degree. |

**TABLE B-4-4**

**COPC LOSS CONSTANT DUE TO RUNOFF**
**(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)**



| Variable | Description | Units | Value |
|---|---|---|---|
| $\theta_{sw}$ | Soil volumetric water content | mL water/cm$^3$ soil | **0.2**<br>This variable is site-specific, and depends on the available water and on soil structure; you can estimate $\theta_{sw}$ as the midpoint between a soil's field capacity and wilting point, if you can identify a representative watershed soil. We recommend using 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 (1998) (no source or reference is provided for this range), and is consistent with U.S. EPA (1994b) and NC DEHNR (1997).<br><br>The following uncertainty is associated with this variable:<br>The default $\theta_{sw}$ value may not accurately reflect site-specific or local conditions; therefore, *ksr* may be under- or overestimated to a small extent, based on the limited range of values. |
| $Z_s$ | Soil mixing zone depth | cm | **2 to 20**<br>We recommend the following values for $Z_s$:<br><br>Soil — Depth (cm) — Reference<br>Untilled — 2 — Brzuzy et al. (1995)<br>Tilled — 20 — U.S. EPA (1998)<br><br>U.S. EPA (1992) recommended values of 1 cm (for untilled) and 20cm (for tilled soil). These values are consistent with U.S. EPA (1998), which further states that leaching soluble compounds might lead to movement below a 1-cm depth. A default value of 2 cm for untilled soil mixing depth is based on a study that profiled dioxin measurements within soil (Brzuzy et al. 1995). A default value of 20 cm for tilled soil mixing depth is based on U.S. EPA (1998).<br><br>The following uncertainties are associated with this variable:<br>(1) For soluble COPCs, leaching might lead to movement to below 2 centimeters in untilled soils, resulting lower concentrations within the $Z_s$. This uncertainty may overestimate *Cs* and $Cs_{tD}$.<br>(2) Deposition to hard surfaces may result in dust residues that have negligible dilution compared to other residues. This uncertainty may underestimate *Cs* and $Cs_{tD}$. |
| $Kd_s$ | Soil-water partition coefficient | mL water/g soil (or cm$^3$ water/g soil) | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail and offer COPC-specific values in Appendix A-2.<br><br>The following uncertainty is associated with this variable:<br>Uncertainties associated with this parameter will be limited if $Kd_s$ values are calculated as described in Appendix A-2. |

## TABLE B-4-4

## COPC LOSS CONSTANT DUE TO RUNOFF
## (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)



| Variable | Description | Units | Value |
|---|---|---|---|
| *BD* | Soil bulk density | g soil/cm$^3$ soil | **1.5**<br>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 (1998). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g soil/cm$^3$ soil, based on a mean value for loam soil obtained from Carsel et al. (1988). U.S. EPA (1998) stated that a value of 1.5 would suffice for most uses, if site-specific information was unavailable.<br><br>The following uncertainty is associated with this variable:<br>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 (1998), 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 (1998) 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.

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:

- Estimating annual current runoff, *RO* (cm/yr), by using the *Water Atlas of the United States* (Geraghty et al. 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 ($\theta_{sw}$)

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. 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.

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 et al. 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 et al. (1988)
- Default soil volumetric water content, $\theta_{sw}$, value of 0.2 (mL water/cm$^3$ soil)

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

This document recommends the following:
- A range of soil volumetric water content, $\theta_{sw}$, 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)
- Using the *Water Atlas of the United States* (Geraghty, Miller, Van der Leeden, and Troise 1973) to calculate average annual runoff, *RO*

**TABLE B-4-5**

**COPC LOSS CONSTANT DUE TO LEACHING**
**(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)**

**(Page 1 of 5)**

**Description**

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

(1) For soluble COPCs, leaching might lead to movement to below 2 centimeters 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) compared to other residues. This uncertainty may underestimate *ksl*.
(3) The original source of this equation has not been identified. U.S. EPA (1998) 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**

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

| Variable | Description | Units | Value |
|---|---|---|---|
| *ksl* | COPC loss constant due to leaching | $yr^{-1}$ | |
| *P* | Average annual precipitation | cm/yr | **18.06 to 164.19**<br>This variable is site-specific. This range is based on information presented in U.S. EPA (1998), representing data for 69 selected cities (U.S. Bureau of Census 1987; Baes et al. 1984). The 69 selected cities are not identified; however, they appear to be located throughout the continental United States. We recommend using site-specific data.<br><br>The following uncertainty is associated with this variable:<br>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, we expect uncertainty introduced by this variable 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**<br>This variable is site-specific. This range is based on information presented in U.S. EPA (1998), representing data for 69 selected cities (Baes et al. 1984). The 69 selected cities are not identified; however, they appear to be located throughout the continental United States.<br><br>The following uncertainty is associated with this variable:<br>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**<br>This variable is site-specific. According to U.S. EPA (1998), U.S. EPA (1994a), and NC DEHNR (1997), you can estimate *RO* by using the *Water Atlas of the United States* (Geraghty et al. 1973). According to NC DEHNR (1997), you can also use 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.<br><br>The following uncertainty is associated with this variable:<br>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**<br>This variable is site-specific. This range is based on information presented in U. S. EPA (1998), representing data from 69 selected cities. The 69 selected cities are not identified; however, they appear to be located throughout the continental United States.<br><br>The following uncertainty is associated with this variable:<br>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-4-5**

**COPC LOSS CONSTANT DUE TO LEACHING**
**(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)**



| Variable | Description | Units | Value |
|---|---|---|---|
| $\theta_{sw}$ | Soil volumetric water content | mL water/cm$^3$ soil | **0.2**<br>This variable is site-specific, and depends on the available water and on soil structure. You can estimate $\theta_{sw}$ as the midpoint between a soil's field capacity and wilting point, if you can identify a representative watershed soil. We recommend using 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 (1998) (no source or reference is provided for this range) and is consistent with U.S. EPA (1994b) and NC DEHNR (1997).<br><br>The following uncertainty is associated with this variable:<br>The default $\theta_{sw}$ 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 | **2 to 20**<br>We recommend the following values for $Z_s$:<br><br>Soil — Depth (cm) — Reference<br>Untilled — 2 — Brzuzy et al. (1995)<br>Tilled — 20 — U.S. EPA (1998)<br><br>U.S. EPA (1992) recommended values of 1 cm (for untilled) and 20cm (for tilled soil). These values are consistent with U.S. EPA (1998), which further states that leaching soluble compounds might lead to movement below a 1-cm depth. A default value of 2 cm for untilled soil mixing depth is based on a study that profiled dioxin measurements within soil (Brzuzy et al. 1995). A default value of 20 cm for tilled soil mixing depth is based on U.S. EPA (1998).<br><br>The following uncertainties are associated with this variable:<br>(1) For soluble COPCs, leaching might lead to movement to below 2 centimeters in untilled soils, resulting in lower concentrations within the $Z_s$. This uncertainty may overestimate *Cs* and $Cs_{tD}$.<br>(2) Deposition to hard surfaces may result in dust residues that have negligible dilution compared to other residues. This uncertainty may underestimate *Cs* and $Cs_{tD}$. |
| *BD* | Soil bulk density | g soil/cm$^3$ soil | **1.5**<br>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 (1998). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g soil/cm$^3$ soil, based on a mean value for loam soil obtained from Carsel et al. (1988). U.S. EPA (1998) stated that a value of 1.5 would suffice for most uses, if site-specific information was unavailable.<br><br>The following uncertainty is associated with this variable:<br>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)**

**(Page 4 of 5)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $Kd_s$ | Soil-water partition coefficient | $cm^3$ water/g soil | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail and offer COPC-specific values in Appendix A-2.<br><br>The following uncertainty is associated with this variable:<br>Uncertainties associated with this parameter will be limited if $Kd_s$ values are calculated as described in Appendix A-2. |

**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 (1998), 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 (1998), U.S. EPA (1994a), and NC DEHNR (1997) as a reference for calculating *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.

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

This document is cited by U.S. EPA (1998) for the statement that *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.

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 either the *Water Atlas of the United States* (Geraghty et al. 1973) or site-specific procedures, such as 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, $\theta_{sw}$

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 cities, as cited in U.S. EPA (1998); 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 et al. (1984) and U.S. Bureau of the Census (1987) as the original sources of this information.

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.

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 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, $\theta_{sw}$, 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 et al. (1988).

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

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.

**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, and was obtained from *Methodology for Assessing Health Risks Associated with Multiple Exposure Pathways to Combustor Emissions* (U.S. EPA 1998). The soil loss constant due to volatilization (*ksv*) is based on gas equilibrium coefficients and gas phase mass transfer. The first order decay constant, *ksv*, is obtained by adapting the Hwang and Falco equation for soil vapor phase diffusion (Hwang and Falco 1986).

Uncertainties associated with this equation include the following:

(1) For soluble COPCs, leaching might lead to movement to below 2 centimeters 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) compared to other residues. This uncertainty may underestimate *ksv*.

**Equation**

$$ksv = \left[\frac{3.1536 \times 10^{7} \cdot H}{Z_s \cdot Kd_s \cdot R \cdot T_a \cdot BD}\right] \cdot \left(\frac{D_a}{Z_s}\right) \cdot \left[1 - \left(\frac{BD}{\rho_{soil}}\right) - \theta_{sw}\right]$$

| Variable | Definition | Units | Value |
|---|---|---|---|
| *ksv* | Constant for COPC loss due to volatilization | $yr^{-1}$ | |
| *3.1536 x 10$^{+07}$* | Units conversion factor | s/yr | |
| *H* | Henry's Law constant | atm-$m^3$/mol | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database.<br><br>The following uncertainty is associated with this variable:<br>Values for this variable, estimated by using the parameters and algorithms in Appendix A-2, may under- or overestimate the actual COPC-specific values. As a result, *ksv* may be under- or overestimated. |

**TABLE B-4-6**

**COPC LOSS CONSTANT DUE TO VOLATILIZATION**
**(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)**



| Variable | Definition | Units | Value |
|---|---|---|---|
| $Z_s$ | Soil mixing zone depth | cm | **2 to 20**<br>We recommend the following values for $Z_s$:<br><br>Soil — Depth (cm) — Reference<br>Untilled — 2 — Brzuzy et al. (1995)<br>Tilled — 20 — U.S. EPA (1998)<br><br>U.S. EPA (1992) recommended values of 1 cm (for untilled) and 20cm (for tilled soil). These values are consistent with U.S. EPA (1998), which further states that leaching soluble compounds might lead to movement below a 1-cm depth. A default value of 2 cm for untilled soil mixing depth is based on a study that profiled dioxin measurements within soil (Brzuzy et al. 1995). A default value of 20 cm for tilled soil mixing depth is based on U.S. EPA (1998).<br><br>The following uncertainties are associated with this variable:<br>(1) For soluble COPCs, leaching might lead to movement to below 2 centimeters in untilled soils, resulting a greater mixing depth. This uncertainty may overestimate *Cs* and $Cs_{tD}$.<br>(2) Deposition to hard surfaces may result in dust residues that have negligible dilution compared to other residues. This uncertainty may underestimate *Cs* and $Cs_{tD}$. |
| $Kd_s$ | Soil-water partition coefficient | $cm^3$ water/g soil | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail and offer COPC-specific values in Appendix A-2.<br><br>The following uncertainty is associated with this variable:<br>Uncertainties associated with this parameter will be limited if $Kd_s$ values are calculated as described in Appendix A-2. |
| $R$ | Universal gas constant | atm-$m^3$/mol-K | **$8.205 \times 10^{-5}$**<br>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)**

**(Page 3 of 5)**

| Variable | Definition | Units | Value |
|---|---|---|---|
| $T_a$ | Ambient air temperature | K | **298**<br>This variable is site-specific. U.S. EPA (1998) also recommends an ambient air temperature of 298 K.<br><br>The following uncertainty is associated with this variable:<br>To the extent that site-specific or local values for the variable are not available, default values may not accurately represent site-specific conditions. We expect the uncertainty associated with the selection of a single value from within the temperature range at a single location 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**<br>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 (1998). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g soil/cm$^3$ soil, based on a mean value for loam soil obtained from Carsel et al. (1988). U.S. EPA (1998) stated that a value of 1.5 would suffice for most uses, if site-specific information was unavailable.<br><br>The following uncertainty is associated with this variable:<br>The recommended soil bulk density value may not accurately represent site-specific soil conditions. |
| $\rho_{soil}$ | Solids particle density | g/cm$^3$ | **2.7**<br>We recommend the use of this value, based on Blake and Hartage (1996) and Hillel (1980).<br>The solids particle density will vary with location and soil type. |
| $D_a$ | Diffusivity of COPC in air | cm$^2$/s | **Varies**<br>This value is COPC-specific. We discuss this variable in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database.<br><br>The following uncertainty is associated with this variable:<br>The default $D_a$ values may not accurately represent the behavior of COPCs under site-specific conditions. However, we expect the degree of uncertainty to be minimal. |

**TABLE B-4-6**

**COPC LOSS CONSTANT DUE TO VOLATILIZATION**
**(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)**

**(Page 4 of 5)**

| Variable | Definition | Units | Value |
|---|---|---|---|
| $\theta_{sw}$ | Soil volumetric water content | mL/cm$^3$ soil | **0.2**<br>This variable depends on the available water and on soil structure. You can estimate $\theta_{sw}$ as the midpoint between a soil's field capacity and wilting point, if you can identify a representative watershed soil. However, we recommend using 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 (1998) (no source or reference is provided for this range) and is consistent with U.S. EPA (1994b).<br><br>The following uncertainty is associated with this variable:<br>The default $\theta_{sw}$ values may not accurately reflect site-specific or local conditions; therefore, *ksv* may be under- or overestimated to a small extent, based on the limited range of values. |

**REFERENCES AND DISCUSSION**


Blake, GR. and K.H. Hartge. 1996. *Particle Density. Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods.* Second Edition. Arnold Klute, Ed. American Society of Agronomy, Inc. Madison, WI., p. 381.

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.

Hwang S. T. and Falco, J. W. 1986. "Estimation of multimedia exposures related to hazardous waste facilities", In: *Pollutants in a Multimedia Environment.* Yoram Cohen, Ed. Plenum Publishing Corp. New York.

Miller, R.W. and D.T. Gardiner. 1998. In: *Soils in Our Environment.* J.U. Miller, Ed. Prentice Hall. Upper Saddle River, NJ. pp. 80-123.

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.

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 et al. (1988).

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

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
- A range of soil volumetric water content, $\theta_{sw}$

**TABLE B-4-7**

**TOTAL WATER BODY LOAD**
**(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)**

**(Page 1 of 2)**

**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 associated with 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, Dytwv, Dytwp,* $A_w$, *Cywv,* $A_p$, $A_L$, *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) We expect the 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 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 using well-established 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 vapor phase COPC direct deposition load to water body | g/yr | **Varies**<br>This variable is COPC- and site-specific, and calculated using the equation presented in Table B-4-8.<br><br>Uncertainty associated with this variable include the following:<br>Most of the uncertainty associated with the variables in the equation in Table B-4-8, specifically those associated with *Q, Dytwv, Dytwp*, and $A_w$, are site-specific and may be significant in some cases. |
| $L_{dif}$ | Vapor phase COPC diffusion load to water body | g/yr | **Varies**<br>This variable is calculated using equation presented in Table B-4-12.<br><br>Uncertainty associated with this variable include the following:<br>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**<br>This variable is calculated using the equation presented in Table B-4-9.<br><br>Uncertainty associated with this variable include the following:<br>Most of the uncertainty associated with the variables in this equation, specifically those associated with *Q, Dytwv, Dytwp*, and $A_I$, are site-specific. |
| $L_R$ | Runoff load from pervious surfaces | g/yr | **Varies**<br>This variable is calculated using equation presented in Table B-4-10.<br><br>Uncertainties associated with this variable include the following:<br>(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.<br>(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**<br>This variable is calculated using equation presented in Table B-4-11.<br><br>Uncertainties associated with this variable include the following:<br>(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.<br>(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 ($Kd_s$). |

### 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 $Q$, $Dytwv$, $Dytwp$ , and $A_w$, are site-specific.
(2) It is calculated assuming 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, using 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, $F_v$ would likely to be only a few percent lower.

**Equation**

$$L_{DEP} = Q \cdot [\, F_v \cdot Dytwv + (1 - F_v) \cdot Dytwp] \cdot A_w$$

For mercury modeling

$$L_{DEP_{(Mercury)}} = (0.48 Q_{(Total)}) \cdot [\, F_{v_{(Hg^{2+})}} \cdot Dytwv + (1 - F_{v_{(Hg^{2+})}}) \cdot Dytwp] \cdot A_w$$

Use $0.48Q$ for total mercury (to account for loss to the global cycle) and $F_v = 0.85$ in the mercury modeling equation.

| Variable | Description | Units | Value |
|---|---|---|---|
| $L_{DEP}$ | Total (wet and dry) particle phase and vapor phase direct deposition load to water body | g/yr | |
| $Q$ | COPC-specific emission rate | g/s | **Varies**<br>This variable is COPC- and site-specific. See Chapters 2 and 3 for guidance on calculating 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**<br>This variable is COPC-specific. We discuss $F_v$ in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database. This range is based on values presented in Appendix A-2. Values are also presented in U.S. EPA (1994b) and NC DEHNR (1997).<br><br>$F_v$ 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).<br><br>The following uncertainties are associated with this variable:<br>(1) It 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, using 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. It would result in a lower calculated $F_v$ value; however, the $F_v$ value is likely to be only a few percent lower.<br>(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 $F_v$. |
| *Dytwv* | Unitized yearly (water body or watershed) average total (wet and dry) deposition from vapor phase | s/m$^2$-yr | **Varies**<br>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**<br>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**<br>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-4-8

## DEPOSITION TO WATER BODY
## (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

## (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 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)**

**(Page 1 of 3)**

**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 $Q$, $Dytwv$, $Dytwp$, 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, using 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**

$$L_{RI} = Q \cdot \left[ F_v \cdot Dytwv + \left(1.0 - F_v\right) \cdot Dytwp \right] \cdot A_I$$

For Mercury modeling

$$L_{RI(Mercury)} = \left(0.48\, Q_{(Total)}\right) \cdot \left[ F_{v(Hg^{2+})} \cdot Dytwv + \left(1.0 - F_{v(Hg^{2+})}\right) \cdot Dytwp \right] \cdot A_I$$

Use $0.48Q$ for total mercury (to account for loss to the global cycle) and $F_v = 0.85$ in the mercury modeling equation.

| Variable | Description | Units | Value |
|---|---|---|---|
| $L_{RI}$ | Runoff load from impervious surfaces | g/yr | |
| $Q$ | COPC-specific emission rate | g/s | **Varies**<br>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**<br>This variable is COPC-specific. We discuss $F_v$ in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database. This range is based on values presented in Appendix A-2. Values are also presented in U.S. EPA (1994b) and NC DEHNR (1997).<br><br>$F_v$ 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).<br><br>The following uncertainties are associated with this variable:<br>(1) Calculations assume 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, using 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.<br>(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 $F_v$. |
| *Dytwv* | Unitized yearly (water body or watershed) average total (wet and dry) deposition from vapor phase | $s/m^2$-yr | **Varies**<br>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**<br>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**<br>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 generally metals are 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 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.

This document is a reference source for the equation in Table B-4-9. This document also presents $F_v$ values for organic COPCs that range form 0.27 to 1. $F_v$ values for organics other than PCDD/PCDFs are calculated 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 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**

$$L_R = RO \cdot (A_L - A_I) \cdot \frac{Cs \cdot BD}{\theta_{sw} + Kd_s \cdot BD} \cdot 0.01$$

| Variable | Description | Units | Value |
|---|---|---|---|
| $L_R$ | Runoff load from pervious surfaces | g COPC/yr | |
| $RO$ | Average annual surface runoff from pervious areas | cm water/yr | **Varies**<br>This variable is site-specific. According to U.S. EPA (1998), 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 et al. 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.<br><br>The following uncertainty is associated with this variable:<br>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**<br>This variable is site-specific. See Chapter 4 for procedures to calculate this variable. Uncertainties associated with this variable are site-specific. |
| $A_I$ | Impervious watershed area receiving COPC deposition | $m^2$ | **Varies**<br>This variable is site-specific. See Chapter 4 for procedures to calculate this variable. Uncertainties associated with this variable are site-specific. |

**TABLE B-4-10**

**PERVIOUS RUNOFF LOAD TO WATER BODY**
**(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)**



| Variable | Description | Units | Value |
|---|---|---|---|
| *Cs* | Average soil concentration over exposure duration | mg COPC/kg soil | **Varies**<br>This variable is COPC- and site-specific, and is calculated using the equation presented in Table B-4-1. Uncertainties associated with this variable are site-specific. |
| *BD* | Soil bulk density | g soil/$cm^3$ soil | **1.5**<br>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 (1998). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g soil/$cm^3$ soil, based on a mean value for loam soil obtained from Carsel et al. (1988). U.S. EPA (1998) stated that a value of 1.5 would suffice for most uses, if site-specific information was unavailable.<br><br>The following uncertainty is associated with this variable:<br>The recommended range of soil bulk density values may not accurately represent site-specific soil conditions. |
| $\theta_{sw}$ | Soil volumetric water content | mL water/$cm^3$ soil | **0.2**<br>This variable depends on the available water and on soil structure; you can estimate $\theta_{sw}$ as the midpoint between a soil's field capacity and wilting point, if a representative watershed soil can be identified. However, we recommend using a default value of 0.2 mL/$cm^3$; 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 (1998) (no source or reference is provided for this range) and is consistent with other U.S. EPA (1994b) and NC DEHNR (1997) guidance.<br><br>The following uncertainty is associated with this variable:<br>The default $\theta_{sw}$ value may not accurately reflect site-specific or local conditions; therefore, $K_R$ may be under- or overestimated to a limited extent. |
| $Kd_s$ | Soil-water partition coefficient | $cm^3$ water/g soil | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail and offer COPC-specific values in Appendix A-2.<br><br>The following uncertainty is associated with this variable:<br>Uncertainties associated with this parameter will be limited if $Kd_s$ values are calculated as described in Appendix A-2. |
| *0.01* | Units conversion factor | $cm^2$ water-kg soil-g COPC/$m^2$-gsoil-mgCOPC | |

## TABLE B-4-10

## PERVIOUS RUNOFF LOAD TO WATER BODY
## (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

## (Page 3 of 4)

### 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.

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 et al. 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 ($\theta_{sw}$)

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. 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 et al. (1988), and (2) a default soil volumetric water content, $\theta_{sw}$, 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-4-10**

**PERVIOUS RUNOFF LOAD TO WATER BODY**
**(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)**

**(Page 4 of 4)**

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

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.

This document is also a source of the following:

- A range of soil volumetric water content ($\theta_{sw}$) 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

**TABLE B-4-11**

**EROSION LOAD TO WATER BODY**
**(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)**

**(Page 1 of 4)**

**Description**

This equation calculates the load to the water body from soil erosion. Uncertainties associated with this equation include the following:

(1) Uncertainties associated with the variables $X_e$, $A_S$, $A_I$, and $Cs$, are site-specific and may be significant in some cases.
(2) Uncertainties associated with the remaining variables aren't 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**

$$L_E = X_e \cdot (A_L - A_I) \cdot SD \cdot ER \cdot \frac{Cs \cdot Kd_s \cdot BD}{\theta_{sw} + Kd_s \cdot BD} \cdot 0.001$$

For mercury modeling, the erosion load to water body is calculated for divalent mercury ($Hg^{2+}$) and methyl mercury (MHg) using their respective $Cs$ values and $Kd_s$ values.

| Variable | Description | Units | Value |
|---|---|---|---|
| $L_E$ | Soil erosion load | g COPC/yr | |
| $X_e$ | Unit soil loss | kg soil/$m^2$-yr | **Varies**<br>This variable is site-specific, and calculated using the equation presented in Table B-4-13.<br><br>The following uncertainty is associated with this variable:<br>All of the equation variables are site-specific. Using 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**<br>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**<br>This variable is site-specific (see Chapter 4). Uncertainties associated with this variable are site-specific. |

**TABLE B-4-11**

**EROSION LOAD TO WATER BODY**
**(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)**



| Variable | Description | Units | Value |
|---|---|---|---|
| *SD* | Watershed sediment delivery ratio | unitless | **Varies**<br>This value is site-specific and calculated using equation in Table B-4-14.<br><br>The following uncertainty is associated with this variable:<br>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 under- or over estimating $L_E$. |
| *ER* | Soil enrichment ratio | unitless | **1 or 3**<br>COPC enrichment occurs because (1) lighter soil particles erode more quickly than heavier soil particles and (2) concentrations of organic COPCs—a function of organic carbon content of sorbing media—are expected to be higher in eroded material than *in situ* soil (U.S. EPA 1998). In the absence of site-specific data, we recommend a default value of 3 for organic COPCs and 1 for inorganic COPCs. This is consistent with other Agency guidance (U.S. EPA 1998), 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 1998); 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 1998).<br><br>The following uncertainty is associated with this variable:<br>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. Using county-specific *ER* values will reduce the extent of any uncertainties. |
| *Cs* | Average soil concentration over exposure duration | mg COPC/kg soil | **Varies**<br>This variable is COPC- and site-specific, and calculated 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**<br>This variable is COPC-specific. We discuss this variable in detail and offer COPC-specific values in Appendix A-2.<br><br>The following uncertainty is associated with this variable:<br>Uncertainties associated with this parameter will be limited if $Kd_s$ values are calculated as described in Appendix A-2. |

**TABLE B-4-11**

**EROSION LOAD TO WATER BODY**
**(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)**

**(Page 3 of 4)**

| Variable | Description | Units | Value |
|---|---|---|---|
| *BD* | Soil bulk density | g soil/cm$^3$ soil | **1.5**<br>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 (1998). U.S. EPA (1994c) recommended a default *BD* value of 1.5 g soil/cm$^3$ soil, based on a mean value for loam soil obtained from Carsel et al. (1988). U.S. EPA (1998) stated that a value of 1.5 would suffice for most uses, if site-specific information was unavailable.<br><br>The following uncertainty is associated with this variable:<br>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. |
| $\theta_{sw}$ | Soil volumetric water content | mL water/cm$^3$ soil | **0.2**<br>This variable is site-specific, and depends on the available water and on soil structure; you can estimate $\theta_{sw}$ as the midpoint between a soil's field capacity and wilting point, if you can identify a representative watershed soil. However, we recommend using 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 (1998) (no source or reference is provided for this range) and is consistent with U.S. EPA (1994b).<br><br>The following uncertainty is associated with this variable:<br>The default $\theta_{sw}$ 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 | mgCOPC/ g COPC | |

## TABLE B-4-11

## EROSION LOAD TO WATER BODY
## (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)

## (Page 4 of 4)

### 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 (1998) 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.

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. 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.

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 et al. (1988), and (2) a default soil volumetric water content, $\theta_{sw}$, value of 0.2 (mL water/cm$^3$ soil).

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. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

This document is the source of a range of COPC enrichment ratio, *ER*, values. The recommended range, 1 to 5, was 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 quickly 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 range of soil volumetric water content ($\theta_{sw}$) 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

**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 vapor phase diffusion. Uncertainties associated with this equation include the following:

(1) Most of the uncertainties associated with the variables $K_v$, $Q$, $Cywv$, 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, using 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

$$L_{dif_{(Mercury)}} = \frac{K_v \cdot (0.48Q_{(Total)}) \cdot F_{v_{(Hg^{2+})}} \cdot Cywv \cdot A_w \cdot 1\times10^{-06}}{\frac{H}{R \cdot T_{wk}}}$$

Use *0.48Q* for total mercury (to account for loss to the global cycle) and $F_v$ = 0.85 in the mercury modeling equation.

| Variable | Description | Units | Value |
|---|---|---|---|
| $L_{dif}$ | Vapor phase diffusion load to water body | g COPC/yr | |
| $K_v$ | Overall transfer rate coefficient | m/yr | **Varies**<br>This variable is COPC- and site-specific, and calculated 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 COPC/s | **Varies**<br>This variable is COPC- and site-specific. See Chapters 2 and 3 for guidance on calculating this variable. Uncertainties associated with this variable are site-specific. |
| $F_v$ | Fraction of COPC air concentration in vapor phase | unitless | **0 to 1**<br>This variable is COPC-specific. We discuss $F_v$ in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database. Values are also presented in U.S. EPA (1994), RTI (1992), and NC DEHNR (1997). Values are based on the work of Bidleman (1988), 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.<br><br>Uncertainties associated with this variable include the following:<br>(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, using 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.<br>(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 average air concentration from vapor phase | µg-s/g-m$^3$ | **Varies**<br>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**<br>This variable is site-specific (see Chapter 4). Uncertainties associated with this variable are site-specific. However, we expect 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)**



| Variable | Description | Units | Value |
|---|---|---|---|
| $H$ | Henry's Law constant | atm-$m^3$/mol | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database.<br><br>The following uncertainty is associated with this variable:<br>Values for this variable, estimated by using the parameters and algorithms in Appendix A-2, 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**<br>This variable is site-specific. We recommend using this default value in the absence of site-specific information, consistent with U.S. EPA (1998) and U.S. EPA (1994).<br><br>The following uncertainty is associated with this variable:<br>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); We assume that this is the case.

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.

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.

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

This document recommends a range (10°C to 20°C, 283 K to 303 K) for water body temperature, $T_{wk}$. No source was identified for this range.

**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 default 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**<br>This value is site-specific and is derived on a storm-by-storm basis. As cited in U.S. EPA (1998), average annual values were compiled regionally by Wischmeier and Smith (1978); the recommended range reflects these compiled values.<br><br>The following uncertainty is associated with this variable:<br>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. |
| $K$ | USLE erodibility factor | ton/acre | **Varies**<br>This value is site-specific. We recommend using current guidance (U.S. Department of Agriculture 1997; U.S. EPA 1985) in determining watershed-specific values for this variable based on site-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 et al. 1989), and chosen to be representative of a whole watershed, not just an agricultural field.<br><br>The following uncertainty is associated with this variable:<br>Using a site-specific USLE soil erodibility factor, $K$, may cause unit soil loss, $X_e$, to be under- or overestimated to some unknown degree. |

**TABLE B-4-13**

**UNIVERSAL SOIL LOSS EQUATION (USLE)**
**(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)**

**(Page 2 of 4)**

| Variable | Description | Units | Value |
|---|---|---|---|
| *LS* | USLE length-slope factor | unitless | **Varies**<br>This value is site-specific. We recommend using current guidance (U.S. Department of Agriculture 1997; U.S. EPA 1985) in determining watershed-specific values for this variable based on site-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.<br><br>The following uncertainty is associated with this variable:<br>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**<br>This value is site-specific. We recommend using current guidance (U.S. Department of Agriculture 1997; U.S. EPA 1985) in determining watershed-specific values for this variable based on site-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 1998). U.S. EPA (1993) 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 recommended a default value of 0.1 to be representative of a whole watershed, not just an agricultural field.<br><br>The following uncertainty is associated with this variable:<br>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, $X_e$. |
| *PF* | USLE supporting practice factor | unitless | **Varies**<br>This value is site-specific. We recommend using current guidance (U.S. Department of Agriculture 1997; U.S. EPA 1985) in determining watershed-specific values for this variable based on site-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 (1998; 1994).<br><br>The following uncertainty is associated with this variable:<br>Using a site-specific USLE supporting practice factor, *PF*, may result in under- or overestimating $X_e$ 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 | |

## TABLE B-4-13

## UNIVERSAL SOIL LOSS EQUATION (USLE)
## (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)



### 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. 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.

This document 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. 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.

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.

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

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 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.

Wischmeier, 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 (1998) as the source of average annual USLE rainfall factors, *RF*, compiled regionally. According to U.S. EPA (1998), 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, using 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, using 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 | |
| *a* | Empirical intercept coefficient | unitless | **0.6 to 2.1**<br>This variable is site-specific and is determined on the basis of the watershed area (Vanoni 1975), as cited in U.S. EPA (1998):<br><br>Watershed Area (sq. miles) / "*a*" Coefficient (unitless)<br>≤0.1 — 2.1<br>1 (>0.1 but ≤1.0) — 1.9<br>10 (>1.0 but ≤10) — 1.4<br>100 (>10 but ≤100) — 1.2<br>1,000 (>100) — 0.6<br><br>Note: 1 sq. mile = 2.59 x $10^6$ $m^2$<br><br>Using these values is consistent with U.S. EPA (1994a), U.S. EPA (1994b), and NC DEHNR (1997).<br><br>The following uncertainty is associated with this variable:<br>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, using these default values may under- or overestimate the watershed sediment delivery ratio, *SD*. |

## TABLE B-4-14

## SEDIMENT DELIVERY RATIO
## (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)



| Variable | Description | Units | Value |
|---|---|---|---|
| $A_L$ | Total watershed area receiving deposition | $m^2$ | **Varies**<br>This variable is site-specific (see Chapter 4). Uncertainties associated with this variable are site-specific. |
| $b$ | Empirical slope coefficient | unitless | **0.125**<br>As cited in U.S. EPA (1998), 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).<br><br>The following uncertainty is associated with this variable:<br>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*. |

### 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. 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.

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.

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.

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

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.

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 (1998) as the source of the equation in Table 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**

$$C_{wtot} = \frac{L_T}{Vf_x \cdot f_{wc} + k_{wt} \cdot A_w \cdot (d_{wc} + d_{bs})}$$

| 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 calculated using the equation in Table B-4-7. Uncertainties associated with $L_{DEP}$, $L_{Dif}$, $L_{RP}$, $L_R$, 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**<br>This variable is site-specific. The following uncertainty is associated with this variable:<br><br>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, using default $Vf_x$ values may contribute to under- or overestimating total water body COPC concentration, $C_{wtot}$. |
| $f_{wc}$ | Fraction of total water body COPC concentration in the water column | unitless | **0 to 1**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-4-16.<br><br>The following uncertainty is associated with this variable:<br>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* $\theta_{bs}$—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, using default values may result in insignificant uncertainty in specific cases. |
| $k_{wt}$ | Overall total water body dissipation rate constant | $yr^{-1}$ | **Varies**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-4-17.<br><br>The following uncertainty is associated with this variable:<br>All of the variables in the equation in Table B-4-17 are site-specific; therefore, using default values for any or all of these variables will contribute to under- or overestimating $C_{wtot}$. 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**<br>This variable is site-specific. The value you select represents an average value for the entire year. See Chapter 4 for procedures to determine this variable.<br><br>Uncertainties associated with this variable are site-specific. However, we expect 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**<br>This variable is site-specific. The value you select represents an average value for the entire year.<br><br>The following uncertainty is associated with this variable:<br>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, using $d_{wc}$ values may contribute to under-or overestimating total water body COPC concentration, $C_{wtot}$. |
| $d_{bs}$ | Depth of upper benthic sediment layer | m | **0.03**<br>This variable is site-specific. The value you select represents an average value for the entire year. We recommend 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. U.S. EPA (1998) suggests a range of values, from 0.01 to 0.05 meters.<br><br>The following uncertainty is associated with this variable:<br>Default $d_{bs}$ values may not accurately represent site-specific water body conditions. However, based on the narrow recommended range, we expect any uncertainty introduced to be limited. |

### 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.

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

This document is cited as the source of a range of values for the depth of the upper benthic layer ($d_{bs}$).

**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:

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 $\theta_{bs}$—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**

$$f_{wc} = \frac{(1 + Kd_{sw} \cdot TSS \cdot 1\times10^{-6}) \cdot d_{wc}/d_z}{(1 + Kd_{sw} \cdot TSS \cdot 1\times10^{-6}) \cdot d_{wc}/d_z + (\theta_{bs} + Kd_{bs} \cdot C_{BS}) \cdot d_{bs}/d_z}$$

$$f_{bs} = 1 - f_{wc}$$

| 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 | |

**TABLE B-4-16**

**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**<br>This variable is COPC-specific. We discuss this variable in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database.<br><br>The following uncertainty is associated with this variable:<br>$Kd_{sw}$ values in the HHRAP companion database 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. You can reduce uncertainty associated with $Kd_{sw}$ by using site-specific and medium-specific *OC* estimates to calculate $Kd_{sw}$. |
| *TSS* | Total suspended solids concentration | mg/L | **2 to 300**<br>This variable is site-specific. We recommend using 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) and U.S. EPA (1993) in the absence of site-specific measured data.<br><br>The following uncertainty is associated with this variable:<br>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 under- or overestimating $f_{wc}$. |
| $\frac{1}{6} \times 10^{-}$ | Units conversion factor | kg/mg | |
| $d_{wc}$ | Depth of water column | m | **Varies**<br>This variable is site-specific. The value you select represents an average value for the entire year.<br><br>The following uncertainty is associated with this variable:<br>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, using $d_{wc}$ values may contribute to under- or overestimating 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**<br>This variable is site-specific. The value you select represents an average value for the entire year. We recommend 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. U.S. EPA (1998) suggests a range of values, from 0.01 to 0.05 meter.<br><br>The following uncertainty is associated with this variable:<br>A default $d_{bs}$ value may not accurately represent site-specific water body conditions. However, we expect any uncertainty introduced to be limited on the basis of the narrow recommended range. |
| $d_z$ | Total water body depth | m | **Varies**<br>This variable is site-specific. We recommend using the following equation to calculate total water body depth, consistent with NC DEHNR (1997):<br><br>$d_z = d_{wc} + d_{bs}$<br><br>The following uncertainty is associated with this variable:<br>Calculating this variable sums the concentrations associated with the two variables $d_{wc}$ 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 we don't expect the uncertainties associated with $d_{wc}$ to be significant, we likewise don't expect the total uncertainties associated with $d_z$ to be significant. |
| $C_{BS}$ | Bed sediment concentration (or bed sediment bulk density) | g/cm$^3$ (equivalent to kg/L) | **1.0**<br>This variable is site-specific. We recommend a default value of 1.0, consistent with U.S. EPA (1998), which states that this value should be reasonable for most applications. The recommended default value is also consistent with other U.S. EPA (1994), and NC DEHNR (1997) guidance.<br><br>The following uncertainty is associated with this variable:<br>The recommended default value may not accurately represent site- and water body-specific conditions. Therefore, the variable $f_{wc}$ may be under- or overestimated. Based on th narrow recommended range, we expect the under- or overestimation will be limited. |

## TABLE B-4-16

## FRACTION IN WATER COLUMN AND BENTHIC SEDIMENT (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)



| Variable | Description | Units | Value |
|---|---|---|---|
| $\theta_{bs}$ | Bed sediment porosity | $L_{water}/L_{sediment}$ | **0.6**<br>This variable is site-specific. We recommend a default bed sediment porosity of 0.6 (by using a $C_{BS}$ value of 1 g/cm$^3$ and a solid density ($\rho_s$) value of 2.65 kg/L) calculated by using the following equation (U.S. EPA 1998):<br>$\theta_{bs} = 1 - C_{BS}/\rho_s$<br>This is consistent with other U.S. EPA (1994), and NC DEHNR (1997) guidance.<br>The following uncertainty is associated with this variable:<br>Calculation of this variable combines the uncertainties associated with the two variables, $C_{BS}$ and $\rho_s$, used in the calculation. To the extent that the recommended default values of $C_{BS}$ and $\rho_s$ don't accurately represent site- and water body-specific conditions, $\theta_{bs}$ 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**<br>This variable is COPC-specific. We discuss this variable in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database.<br>The following uncertainty is associated with this variable:<br>The $Kd_{bs}$ values in the HHRAP companion database 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 $Kd_{bs}$. |

### 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
*TSS* values. This document cites U.S. EPA (1993b) as its source of information.
the equation for calculating total water body depth. No source of this equation was identified.
the default value for bed sediment porosity. This document cites U.S. EPA (1993b) as its source of information.
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.
the default bed sediment concentration. This document cites U.S. EPA (1993b) as its source of information.

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.

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 $C_{BS}$, 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.

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.
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.
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.

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

This document is cited as one of the sources of
the equation for calculating bed sediment porosity ($\theta_{bs}$); no source of this equation was identified.
the range of the bed sediment concentration ($C_{BS}$); no original source of this range was identified.

## 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, using default values for any or all of these variables will contribute to under- or overestimating $k_{wt}$. We expect the uncertainty associated with the variable $k_b$ to be one order of magnitude at most. This uncertainty is associated with the estimation of the unit soil loss, $X_e$ (a component of $k_b$). 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**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-4-16.<br><br>Uncertainties associated with this variable include the following:<br>(1) The default variable values we recommend you use in the equation in Table B-4-16 may not accurately represent site-specific water body conditions. However, the ranges of several component variables—including $d_{bs}$, $C_{BS}$, and $\theta_{sw}$—are moderate (factors of 5, 3, and 2, respectively). We therefore expect the degree of uncertainty associated with these variables to be moderate. You can reasonably estimate other variables, such as $d_{wc}$ and $d_z$, using generally available information. We therefore expect the degree of uncertainty associated with these variables to be relatively small.<br>(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**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-4-18.<br><br>Uncertainties associated with this variable include the following:<br>(1) All of the variables in the equation in Table B-4-18 are site-specific. Therefore, using default values for any or all of these variables could contribute to under- or overestimating $k_v$.<br>(2) We expect the degree of uncertainty associated with $k_v$ components $d_z$ and *TSS* to be minimal, either because information needed to estimate these variables is generally available or because the range of likely values is narrow.<br>(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**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-4-16.<br><br>Uncertainties associated with this variable include the following:<br>(1) The default variable values we recommend you use in the equation in Table B-4-16 may not accurately represent site-specific water body conditions. However, the ranges of several components—including $d_{bs}$, $C_{BS}$, and $\theta_{sw}$—are relatively narrow. We therefore expect the degree of uncertainty associated with these variables to be relatively small. You can reasonably estimate other components, such as $d_{wc}$ and $d_z$, using generally available information.<br>(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**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-4-22.<br><br>Uncertainties associated with this variable include the following:<br>(1) All of the variables in the equation in Table B-4-22 are site-specific. Therefore, using default values rather than site-specific values, for any or all of these variables, will contribute to under- or overestimating $K_b$.<br>(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, using default values for any or all of these variables will contribute to under- or over estimating $k_v$. We expect the uncertainty associated with the variables $d_{wc}$, $d_{bs}$, and $d_z$ 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**

$$k_v = \frac{K_v}{d_z \cdot (1 + Kd_{sw} \cdot TSS \cdot 10^{-6})}$$

| Variable | Description | Units | Value |
|---|---|---|---|
| $k_v$ | Water column volatilization rate constant | $yr^{-1}$ | |
| $K_v$ | Overall COPC transfer rate coefficient | m/yr | **Varies**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-4-19.<br><br>Uncertainties associated with this variable include the following:<br>(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, using default values, for any or all these variables, could contribute to under- or overestimating $K_v$.<br>(2) We expect the degree of uncertainty associated with the variables *H* and $T_{wk}$ to be minimal. Values for *H* are well-established, and $T_{wk}$ will likely vary less than 10 percent of the default value.<br>(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, using default values may generate significant uncertainty in specific instances. Finally, the origin of the recommended temperature correction factor, θ, value is unknown. The degree of associated uncertainty is therefore 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**<br>This variable is site-specific. We recommend using the following equation to calculate $d_z$, consistent with NC DEHNR (1997):<br>$d_z = d_{wc} + d_{bs}$<br>The following uncertainty is associated with this variable:<br>Calculating this variable sums the concentrations associated with the two variables $d_{wc}$ 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 we don't expect the uncertainties associated with $d_{wc}$ to be significant, we likewise don't expect the total uncertainties associated with $d_z$, to be significant. |
| $d_{wc}$ | Depth of water column | m | **Varies**<br>This variable is site-specific.<br>The following uncertainty is associated with this variable:<br>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, using default $d_{wc}$ values may contribute to under- or overestimating total water body COPC concentration, $C_{wtot}$. However, we don't expect the degree of under- or overestimating to be significant. |
| $d_{bs}$ | Depth of upper benthic sediment layer | m | **0.03**<br>This variable is site-specific. The value you select represents an average value for the entire year. We recommend 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. U.S. EPA (1998) suggests a range of values, from 0.01 to 0.05 meter.<br>The following uncertainty is associated with this variable:<br>A default $d_{bs}$ value may not accurately represent site-specific water body conditions. However, we expect any uncertainty introduced to be limited on the basis of 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**<br>This variable is COPC-specific. We discuss this variable in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database.<br><br>The following uncertainty is associated with this variable:<br>The $Kd_{sw}$ values presented in the HHRAP companion database were 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. You can reduce uncertainty associated with this variable by using site-specific and medium-specific *OC* estimates to calculate $Kd_{sw}$. |
| *TSS* | Total suspended solids concentration | mg/L | **2 to 300**<br>This variable is site-specific. We recommend using 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) and U.S. EPA (1993) in the absence of site-specific measured data.<br><br>The following uncertainty is associated with this variable:<br>Limitation on measured data used to determine 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 under-or overestimating $f_{wc}$. |
| $1 \times 10^{-6}$ | 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. 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.

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.

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

## TABLE B-4-19

## 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, using default values for any or all of these variables will contribute to under- or overestimating $K_v$.

(2) We believe the degree of uncertainty associated with the variables $H$ and $T_{wk}$ to be minimal. Values for $H$ are well-established, and $T_{wk}$ 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, using 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**

$$K_v = \left[ K_L^{-1} + \left( K_G \cdot \frac{H}{R \cdot T_{wk}} \right)^{-1} \right]^{-1} \cdot \theta^{(T_{wk} - 293)}$$

| Variable | Description | Units | Value |
|---|---|---|---|
| $K_v$ | Overall COPC transfer rate coefficient | m/yr | |

**TABLE B-4-19**

**OVERALL COPC TRANSFER RATE COEFFICIENT**
**(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)**



| Variable | Description | Units | Value |
|---|---|---|---|
| $K_L$ | Liquid phase transfer coefficient | m/yr | **Varies**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-4-20.<br><br>Uncertainties associated with this variable include the following:<br>All of the variables in the equation in Table B-4-20 are site-specific. Therefore, using default values rather than site-specific values, for any or all of these variables, will contribute to under- or overestimating $K_v$. The degree of uncertainty associated with these variables is as follows:<br>a) We assume the uncertainty associated with six variables—$D_w$, $u$, $d_z$, $\rho_a$, $\rho_w$, and $\mu_w$—is minimal or insignificant, either because of narrow recommended ranges for these variables or because information to estimate variable values is generally available.<br>b) No original sources were identified for the equations used to derive recommended values or specific recommended values for variables $C_d$, $k$, and $\lambda_z$. Therefore, the degree and direction of any uncertainties associated with these variables are unknown.<br>c) Uncertainties associated with the variable $W$ are site-specific. |
| $K_G$ | Gas phase transfer coefficient | m/yr | **Varies**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-4-21.<br><br>Uncertainties associated with this variable include the following:<br>All of the variables in the equation in Table B-4-21, with the exception of $k$, are site-specific. Therefore, using default values rather than site-specific values, for any or all of these variables, will contribute to under- or overestimating $K_G$. The degree of uncertainty associated with each of these variables is as follows:<br>a) We assume the uncertainty associated with the variables $D_a$, $\mu_a$, and $\rho_a$, is minimal or insignificant, because these variables have been extensively studied, and equation procedures are well-established.<br>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.<br>c) Uncertainties associated with the variable $W$ are site-specific and cannot be readily estimated. |
| $H$ | Henry's Law constant | atm-$m^3$/mol | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database.<br><br>The following uncertainty is associated with this variable:<br>Values for this variable, estimated using the parameters and algorithms in Appendix A-2, may under- or overestimate the actual COPC-specific values. As a result, $K_v$ may be under- or overestimated to a limited degree. |

**TABLE B-4-19**

**OVERALL COPC TRANSFER RATE COEFFICIENT**
**(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)**

**(Page 3 of 3)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $R$ | Universal gas constant | atm-$m^3$/mol-K | **$8.205 \times 10^{-5}$**<br>There are no uncertainties associated with this constant. |
| $T_{wk}$ | Water body temperature | K | **298**<br>This variable is site-specific. We recommend using this default value when site-specific information is not available; this is consistent with U.S. EPA (1994) and U.S. EPA (1998).<br><br>The following uncertainty is associated with this variable:<br>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. |
| θ | Temperature correction factor | unitless | **1.026**<br>This variable is site-specific. We recommend using this default value when site-specific information is not available. This is consistent with U.S. EPA (1994) and U.S. EPA (1998).<br><br>The following uncertainty is associated with this variable:<br>The purpose and sources of this variable and the recommended value are unknown. |

**REFERENCES AND DISCUSSION**

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.

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

This document is the reference source for the equation in Table B-4-19. This document also recommends the $T_{wk}$ value of 298 K (298 K = 25°C) and the θ value of 1.026. No source was identified for these values.

**TABLE B-4-20**

**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) We assume uncertainly associated with the following six variables is minimal or insignificant: $D_w$, $u$, $d_z$, $\rho_a$, $\rho_w$, *and* $\mu_w$.
(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

$$K_L = (C_d^{0.5} \cdot W) \cdot \left(\frac{\rho_a}{\rho_w}\right)^{0.5} \cdot \frac{k^{0.33}}{\lambda_z} \cdot \left(\frac{\mu_w}{\rho_w \cdot D_w}\right)^{-0.67} \cdot 3.1536 \times 10^7$$

| 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)**



| Variable | Description | Units | Value |
|---|---|---|---|
| $D_w$ | Diffusivity of COPC in water | $cm^2/s$ | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database.<br><br>The following uncertainty is associated with this variable:<br>The default $D_w$ values may not accurately represent the behavior of COPCs under water body-specific conditions. However, we expect the degree of uncertainty to be minimal. |
| $u$ | Current velocity | m/s | **Varies**<br>This variable is site-specific, and relates to the volumetric flow rate of the waterbody evaluated.<br><br>The following uncertainty is associated with this variable:<br>Sources of values for this variable are reasonably available for most large surface water bodies. Estimated values for this variable may be necessary for smaller water bodies; uncertainty will be associated with these estimates. We don't expect the degree of uncertainty associated with this variable to be significant. |
| $d_z$ | Total water body depth | m | **Varies**<br>This variable is site-specific, and, in most cases, represents the average mean across the waterbody evaluated. We recommend that you calculate this value using the following equation, consistent with U.S. EPA (1994) and NC DEHNR (1997):<br><br>$d_z = d_{wc} + d_{bs}$<br><br>No reference was cited for this recommendation.<br><br>The following uncertainty is associated with this variable:<br>Calculating this variable sums the concentrations associated with the two variables $d_{wc}$ 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, we likewise don't expect the total uncertainties associated with $d_z$ to be significant. |
| $3.1536 \times 10^7$ | Units conversion factor | s/yr | |

**TABLE B-4-20**

**LIQUID PHASE TRANSFER COEFFICIENT**
**(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)**



| Variable | Description | Units | Value |
|---|---|---|---|
| $C_d$ | Drag coefficient | unitless | **0.0011**<br>This variable is site-specific. We recommend a default value of 0.0011, consistent with U.S. EPA (1994), NC DEHNR (1997), and U.S. EPA (1998).<br><br>The following uncertainty is associated with this variable:<br>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**<br>Consistent with U.S. EPA (1998), we recommend 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.<br><br>The following uncertainty is associated with this variable:<br>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. |
| $\rho_a$ | Density of air | $g/cm^3$ | **0.0012**<br>We recommend 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).<br><br>The density of air will vary with temperature. |
| $\rho_w$ | Density of water | $g/cm^3$ | **1**<br>We recommend 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. |
| $k$ | von Karman's constant | unitless | **0.4**<br>This value is a constant. We recommend using this value, consistent with U.S. EPA (1994) and NC DEHNR (1997).<br><br>The following uncertainty is associated with this variable:<br>The original source of this variable value is unknown. Therefore, any uncertainties associated with its use are also unknown. |

**TABLE B-4-20**

**LIQUID PHASE TRANSFER COEFFICIENT**
**(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)**



| Variable | Description | Units | Value |
|---|---|---|---|
| $\lambda_z$ | Dimensionless viscous sublayer thickness | unitless | **4**<br>This value is site-specific. We recommend using this default value when site-specific information is not available; consistent with U.S. EPA (1994) and NC DEHNR (1997).<br><br>The following uncertainty is associated with this variable:<br>The source of the value for this variable is unknown. Therefore, any uncertainties associated with its use cannot be quantified. |
| $\mu_w$ | Viscosity of water corresponding to water temperature | g/cm-s | **$1.69 \times 10^{-02}$**<br>We recommend 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 $C_d$, $\rho_a$, $\rho_w$, $k$, $\alpha_\lambda$, and $\mu_w$ values of 0.0011, $1.2 \times 10^{-3}$, 1, 0.4, 4, and $1.69 \times 10^{-2}$, respectively. This document cites (1) Weast (1979) as its source of information regarding $\rho_a$, $\rho_w$, and $\mu_w$; 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. 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 $C_d$, $\rho_a$, $\rho_w$, $k$, $\lambda_z$, and $\mu_w$ values of 0.0011, $1.2 \times 10^{-3}$, 1, 0.4, 4, and $1.69 \times 10^{-2}$, respectively. This document cites (1) Weast (1979) as its source of information regarding $\rho_a$, $\rho_w$, and $\mu_w$; 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.

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

This document recommends a value of 0.0011 for the drag coefficient ($C_d$) variable and a value of 0.4 for von Karman's constant ($k$). No sources are cited for these values.

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 $\rho_a$, $\rho_w$, and $\mu_w$ variables of $1.2 \times 10^{-3}$, 1, and $1.69 \times 10^{-2}$, 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 $D_a$, $\mu_a$, and $\rho_a$.
(2) No original sources were identified for equations used to derive recommended values or specific recommended values for variables $C_d$, $k$, and $\lambda_z$. 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

$$K_G = (C_d^{0.5} \cdot W) \cdot \frac{k^{0.33}}{\lambda_z} \cdot \left(\frac{\mu_a}{\rho_a \cdot D_a}\right)^{-0.67} \cdot 3.1536\times10^7$$

| Variable | Description | Units | Value |
|---|---|---|---|
| $K_G$ | Gas phase transfer coefficient | m/yr | |
| $C_d$ | Drag coefficient | unitless | **0.0011**<br>This variable is site-specific. We recommend using this default value when site-specific information is not available, consistent with U.S. EPA (1994), NC DEHNR (1997), and U.S. EPA (1998).<br><br>The following uncertainty is associated with this variable:<br>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 speed | m/s | **3.9**<br>Consistent with U.S. EPA (1998), we recommend a default value of 3.9 m/s. See Chapter 3 of the HHRAP for guidance regarding the references and methods used to determine a site-specific value that is consistent with air dispersion modeling.<br><br>The following uncertainty is associated with this variable:<br>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**<br>This value is a constant. We recommend using this value, consistent with U.S. EPA (1994) and NC DEHNR (1997).<br><br>The following uncertainty is associated with this variable:<br>The original source of this variable is unknown. Therefore, any uncertainties associated with its use are also unknown. |
| $\lambda_z$ | Dimensionless viscous sublayer thickness | unitless | **4**<br>This value is site-specific. We recommend using this default value when site-specific information is not available, consistent with U.S. EPA (1994) and NC DEHNR (1997).<br><br>The following uncertainty is associated with this variable:<br>The original source of this variable is unknown. Therefore, any uncertainties associated with its use are also unknown. |
| $\mu_a$ | Viscosity of air | g/cm-s | **$1.81 \times 10^{-04}$**<br>We recommend using 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. |
| $\rho_a$ | Density of air | $g/cm^3$ | **0.0012**<br>We recommend using 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) .<br><br>The density of air will vary with temperature. |

## TABLE B-4-21

## GAS PHASE TRANSFER COEFFICIENT
## (CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)



| Variable | Description | Units | Value |
|---|---|---|---|
| $D_a$ | Diffusivity of COPC in air | $cm^2/s$ | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database.<br><br>The following uncertainty is associated with this variable:<br>The recommended $D_a$ values may not accurately represent the behavior of COPCs under water body-specific conditions. However, we expect the degree of uncertainty to be minimal. |
| $3.1536 \times 10^7$ | 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 $\rho_a$, $k$, $\lambda_z$, and $\mu_a$ values of $1.2 \times 10^{-3}$, 0.4, 4, and $1.81 \times 10^{-04}$, respectively. This document cites (1) Weast (1979) as its source of information for $\rho_a$ and $\mu_a$, and (2) U.S. EPA (1993a) as its source of information for $k$ and $\lambda_z$.

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.

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 ($\lambda_z$) value of 4. The original sources of these 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 $\rho_a$, $k$, $\lambda_z$, and $\mu_a$ values of $1.2 \times 10^{-3}$, 0.4, 4, and $1.81 \times 10^{-04}$, respectively. This document cites (1) Weast (1979) as its source of information for $\rho_a$ and $\mu_a$, and (2) U.S. EPA (1993a) as its source of information for $k$ and $\lambda_z$.

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.

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

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 ($\lambda_z$) variable. The original sources of the variable values are not identified.

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 $\rho_a$, $\rho_w$, and $\mu_a$ variables of $1.2 \times 10^{-3}$, 1, and $1.69 \times 10^{-2}$, respectively.

## TABLE B-4-22

## 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, using default values rather than site-specific values, for any or all of these variables, will contribute to under- or overestimating $k_b$. 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) $C_{BS}$, $d_{bs}$, $V_{fx}$, $TSS$, 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**

$$k_b = \left( \frac{X_e \cdot A_L \cdot SD \cdot 1 \times 10^3 - Vf_x \cdot TSS}{A_w \cdot TSS} \right) \cdot \left( \frac{TSS \cdot 1 \times 10^{-6}}{C_{BS} \cdot d_{bs}} \right)$$

| Variable | Description | Units | Value |
|---|---|---|---|
| $k_b$ | Benthic burial rate constant | $yr^{-1}$ | |
| $X_e$ | Unit soil loss | $kg/m^2\text{-}yr$ | **Varies**<br>This variable is site-specific and is calculated using the equation in Table B-4-13.<br><br>The following uncertainty is associated with this variable:<br>All of the variables in the equation used to calculate unit soil loss, $X_e$, are site-specific. Using 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. We expect the degree or magnitude of any under- or overestimation to be about one order of magnitude or less. |
| $A_L$ | Total watershed area receiving deposition | $m^2$ | **Varies**<br>This variable is site-specific (see Chapter 4). Uncertainties associated with this variable are site-specific. |

**TABLE B-4-22**

**BENTHIC BURIAL RATE CONSTANT**
**(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)**



| Variable | Description | Units | Value |
|---|---|---|---|
| *SD* | Watershed sediment delivery ratio | unitless | **Varies**<br>This value is site-specific and is calculated using the equation in Table B-4-14.<br><br>Uncertainties associated with this variable include the following:<br>(1) The default values for empirical intercept coefficient (*a*) that we recommend 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, using these default values may contribute to under- or overestimating the benthic burial rate constant, $k_b$.<br>(2) The default value for empirical slope coefficient (*b*) that we recommend 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, using this default value may contribute to under-or overestimating $k_b$. |
| $1 \times 10^3$ | Units conversion factor | g/kg | |
| $Vf_x$ | Average volumetric flow rate through water body | $m^3$/yr | **Varies**<br>This variable is site-specific. We recommend using site- and waterbody-specific measured values, representative of long-term average annual values for the water body of concern.<br><br>The following uncertainty is associated with this variable:<br>Default average volumetric flow rate ($Vf_x$) values may not accurately represent site-specific water body conditions. Therefore, using such default values may contribute to under- or overestimating $k_b$. However, we expect that the uncertainty associated with this variable to be limited, because resources such as maps, aerial photographs, and gauging station measurements—from which $Vf_x$ can be estimated—are generally available. |
| *TSS* | Total suspended solids concentration | mg/L | **2 to 300**<br>This variable is site-specific. We recommend using 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), and U.S. EPA (1993) in the absence of site-specific measured data.<br><br>The following uncertainty is associated with this variable:<br>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 under-or overestimating $f_{wc}$. |

**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**<br>This variable is site-specific. The value selected represents 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, we expect 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. |
| $1 \times 10^{-6}$ | Units conversion factor | kg/mg | |
| $C_{BS}$ | Bed sediment concentration | $g/cm^3$ | **1.0**<br>This variable is site-specific. We recommend a default value of 1.0, consistent with U.S. EPA (1998), 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 (1994), and NC DEHNR (1997).<br><br>The following uncertainty is associated with this variable:<br>The recommended value may not accurately represent site-specific water body conditions. |
| $d_{bs}$ | Depth of upper benthic sediment layer | m | **0.03**<br>This variable is site-specific. The value selected represents an average value for the entire year. We recommend a default upper-benthic sediment depth of 0.03 meters, which is based on the center of the range cited by U.S. EPA (1993). This value is also consistent with U.S. EPA (1994) and NC DEHNR (1997).<br><br>The following uncertainty is associated with this variable:<br>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. |

**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 all recommended specific $C_{BS}$ and $d_{bs}$ values. This document cites U.S. EPA (1993a) as its source.

U.S. EPA. 1993. *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.

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 ($\lambda_z$) value of 4. The original sources of these variable values are not identified.

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.

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

## 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, using default values rather than site-specific values, for any or all of these variables, will contribute to under- or overestimating $C_{wctot}$.

We expect the degree of uncertainty associated with the variables $d_{wc}$ and $d_{bs}$ 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**

$$C_{wctot} = f_{wc} \cdot C_{wtot} \cdot \frac{d_{wc} + d_{bs}}{d_{wc}}$$

| 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**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-4-16.<br><br>The following uncertainty is associated with this variable:<br>The default variable values we recommend you 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 $\theta_{sw}$—are relatively narrow. Therefore, we expect the uncertainty to be relatively small. You can reasonably estimate other variables, such as $d_{wc}$ and $d_z$, using 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. |

**TABLE B-4-23**

**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**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-4-15.<br><br>The following uncertainty is associated with this variable:<br>The default variable values we recommend you use in the equation in Table B-4-15 may not accurately represent site--specific water body conditions. We expect the degree of uncertainty associated with variables $Vf_x$, $A_w$, $d_w$, and $d_{bs}$ 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 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 combination of many variable-specific uncertainties. |
| $d_{wc}$ | Depth of water column | m | **Varies**<br>This variable is site-specific. The following uncertainty is associated with this variable:<br>Default values for depth of water column, $d_{wc}$, may not accurately reflect site-specific water body conditions. Therefore, using default values may contribute to under- or overestimating $C_{wctot}$. However, we expect the degree of uncertainty associated with this variable to be limited, because information regarding this variable is generally available. |
| $d_{bs}$ | Depth of upper benthic sediment layer | m | **0.03**<br>This variable is site-specific. We recommend a default upper-benthic sediment depth of 0.03 meters, which is based on the center of a range cited by U.S. EPA (1993) This value is consistent with U.S. EPA (1994) and NC DEHNR (1997).<br><br>The following uncertainty is associated with this variable:<br>The recommended default value for depth of upper benthic sediment layer, $d_{bs}$, may not accurately represent site-specific water body conditions. Therefore, using this default value may contribute to under- or overestimating $C_{wctot}$. However, we expect the degree of uncertainty associated with this variable 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. 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.

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. 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.

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 (1993) 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.

## 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, using default values rather than site-specific values, for any or all of these variables, will contribute to under- or overestimating $C_{dw}$. We expect the degree of uncertainty associated with *TSS* 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,

$$C_{dw(Mercury)} = \frac{C_{wctot(Hg^{2+})}}{1 + Kd_{sw(Hg^{2+})} \cdot TSS \cdot 1 \times 10^{-6}}$$

Use the equation above to calculate the $C_{dw}$ mercury value. Apportion into the divalent mercury ($Hg^{2+}$) and methyl mercury (MHg) forms based on the assumed 85% $Hg^{2+}$ and 15% MHg speciation split in the water body (see Chapter 2) using the correlations below. 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, assume elemental mercury in the water body is negligible or zero, and evaluate it for the direct inhalation pathway only (Table B-5-1).

$$C_{dw\ (Hg2+)} = 0.85\ C_{\text{dw (Mercury)}}$$
$$C_{dw\ (Mhg)} = 0.15\ C_{\text{dw (Mercury)}}$$
$$C_{dw\ (Hg0)} = 0.0$$

Evaluate divalent and methyl mercury as individual COPCs to determine $C_{fish}$ (Tables B-4-26 and B-4-27) for calculating COPC intake from fish in Table C-1-4, and in evaluating COPC intake from drinking water (Table C-1-5). Calculate $C_{dw\ (Mercury)}$ as above using the corresponding fate and transport parameters for mercuric chloride ($Hg^{2+}$) provided in Appendix A-2, and determine $C_{dw\ (Hg2+)}$ and $C_{dw\ (Mhg)}$ as calculated above.

**TABLE B-4-24**

**DISSOLVED PHASE WATER CONCENTRATION**
**(CONSUMPTION OF DRINKING WATER AND FISH EQUATIONS)**



| 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**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-4-23.<br><br>The following uncertainty is associated with this variable:<br>All of the variables in the equation in Table B-4-23 are COPC- and site-specific. Therefore, using default values rather than site-specific values, for any or all of these variables, will contribute to under- or overestimating $C_{wctot}$.<br><br>We expect the degree of uncertainty associated with the variables $d_{wc}$ and $d_{bs}$ 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. |
| $Kd_{sw}$ | Suspended sediments/surface water partition coefficient | L water/kg suspended sediment | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database.<br><br>The following uncertainty is associated with this variable:<br>Values contained in Appendix A-2 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**<br>This variable is site-specific. We recommend using 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) and U.S. EPA (1993b) in the absence of site-specific measured data.<br><br>The following uncertainty is associated with this variable:<br>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 under-or overestimating $f_{wc}$. |
| $1 \times 10^{-6}$ | Units conversion factor | kg/mg | |

**TABLE B-4-24**

**DISSOLVED PHASE WATER 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 $Kd_s$ values and the *TSS* value of 10. This document cites U.S. EPA (1993) as its sources of information regarding *TSS*, and (2) RTI (1992) as its source regarding $Kd_s$.

U.S. EPA. 1993. *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.

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. 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.

## TABLE B-4-25

## 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. We expect the degree of uncertainty associated with variables $\theta_{bs}$, $C_{BS}$, $d_{wc}$, and $d_{bs}$ 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**

$$C_{sb} = f_{bs} \cdot C_{wtot} \cdot \frac{Kd_{bs}}{\theta_{bs} + Kd_{bs} \cdot C_{BS}} \cdot \frac{d_{wc} + d_{bs}}{d_{bs}}$$

| 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**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-4-16.<br><br>The following uncertainty is associated with this variable:<br>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 $\theta_{bs}$—is relatively narrow. You can reasonably estimate other variables, such as $d_{wc}$ and $d_z$, using 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, using default values may result in significant uncertainty in specific cases. |

**TABLE B-4-25**

**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**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-4-15.<br><br>The following uncertainty is associated with this variable:<br>(1) The default variable values may not accurately represent site-specific water body conditions. We expect the degree of uncertainty associated with variables $Vf_x$, $A_w$, $d_{wc}$, and $d_{bs}$ to be limited either because the probable ranges for these variables are narrow or information allowing reasonable estimates is generally available.<br>(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 combination 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**<br>This variable is COPC-specific. We discuss this variable in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database.<br><br>The following uncertainty is associated with this variable:<br>The default $Kd_{bs}$ values in Appendix A-2 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. |
| $\theta_{bs}$ | Bed sediment porosity | unitless<br><br>($L_{pore\ volume}/L_{sediment}$) | **0.6**<br>This variable is site-specific. We recommend a default bed sediment porosity of 0.6 (using a $C_{BS}$ value of 1 g/$cm^3$ and a solids density ($\rho_s$) value of 2.65 kg/L), calculated using the following equation (U.S. EPA 1998):<br><br>$\theta_{bs} = 1 - C_{BS}/\rho_s$<br><br>This also is consistent with U.S. EPA (1993), U.S. EPA (1994), and NC DEHNR (1997).<br><br>The following uncertainty is associated with this variable:<br>To the extent that the recommended default values of $C_{BS}$ and $\rho_s$ don't accurately represent site- and water body-specific conditions, $\theta_{bs}$ will be under- or overestimated to some degree. However, we expect the degree of uncertainty 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)**

**(Page 3 of 4)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $C_{BS}$ | Bed sediment concentration (or bed sediment bulk density) | g/cm$^3$ | **1.0**<br>This variable is site-specific. We recommend a default value of 1.0, consistent with U.S. EPA (1998), 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 (1993), U.S. EPA (1994), and NC DEHNR (1997).<br><br>The following uncertainty is associated with this variable:<br>The recommended default value for $\theta_{bs}$ 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**<br>This variable is site-specific.<br><br>The following uncertainty is associated with this variable:<br>Default $d_{wc}$ values may not accurately reflect site-specific conditions. Therefore, using these values may contribute to under- or overestimating the variable $C_{sb}$. However, we expect the degree of uncertainty 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**<br>This variable is site-specific. We recommend a default upper-benthic sediment depth of 0.03 meters, which is based on the center of a range cited by U.S. EPA (1998). This value is consistent with U.S. EPA (1994) and NC DEHNR (1997).<br><br>The following uncertainty is associated with this variable:<br>Default $d_{bs}$ values may not accurately reflect site-specific conditions. Therefore, using these values may contribute to under- or overestimating $C_{sb}$. However, we expect the degree of uncertainty 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($\theta_{sw}$). 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. 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.

This document is cited by NC DEHNR (1997) and U.S. EPA (1994) as the source of the default bed sediment porosity value ($\theta_{sw}$), 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.

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 ($\theta_{sw}$). 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.

U.S. EPA. 1998. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

This document is also cited as the source of the equation for calculating bed sediment porosity ($\theta_{sw}$). 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.

**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:

Calculating $C_{dw}$ 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**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-4-24.<br><br>Uncertainties associated with this variable include the following:<br>(1) The variables in the equation in Table B-4-24 are site-specific. Therefore, using default values rather than site-specific values, for any or all of these variables, will contribute to the under- or overestimating $C_{dw}$. We expect the degree of uncertainty associated with *TSS* to be relatively small, because information regarding reasonable site-specific values for this variable is generally available or can be easily measured.<br>(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. |

**TABLE B-4-26**

**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<br><br>([mg COPC/kg FW tissue]/[mg COPC/kg feed]) | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database.<br><br>As explained in Appendix A-2, we recommend 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), we obtained values from U.S. EPA (1998) or, when measured values were not available, derived from the correlation equation presented by Lyman et al. (1982).<br><br>The following uncertainty is associated with this variable:<br>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 Ogata et al. (1984), U.S. EPA (1994, 1995) 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.

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.

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. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions.*" Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December. Environmental Criteria and Assessment Office. ORD. Cincinnati, Ohio.

U.S. EPA. 1999. *Screening Level Ecological Risk Assessment Protocol for Hazardous Waste Combustion Facilities.* Peer Review Draft. Office of Solid Waste. August.

**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:

Calculating $C_{dw}$ uses on default values for variables $F_{water}$ and $C_{wtot}$. Values for these two variables, in turn, depend 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 is calculated for divalent mercury ($Hg^{2+}$) and methyl mercury (MHg) as shown in the following equations:

$$C_{fish_{(Hg^{2+})}} = C_{dw_{(Hg^{2+})}} \cdot BAF_{fish_{(Hg^{2+})}}$$

$$C_{fish_{(MHg)}} = C_{dw_{(MHg)}} \cdot BAF_{fish_{(MHg)}}$$

| 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**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-4-24.<br><br>Uncertainties associated with this variable include the following:<br>(1) The variables in the equation in Table B-4-24 are site-specific. Therefore, using default values rather than site-specific values, for any or all of these variables, will contribute to under- or overestimating $C_{dw}$. We expect the degree of uncertainty associated with *TSS* to be relatively small, because information regarding reasonable site-specific values for this variable is generally available or can be easily measured.<br>(2) The uncertainty associated with the variables $C_{wctot}$ and $Kd_{sw}$ depends 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**<br>This variable is COPC-specific. We discuss this variable in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database. As discussed in Appendix A-2, $BAF_{fish}$ values were adjusted for dissolved water concentrations.<br><br>We obtained BAFs for all organics with a log $K_{ow}$ greater than or equal to 4.0 from U.S. EPA (1998), which cites U.S. EPA (1995a), U.S. EPA (1995b), and U.S. EPA (1994b). We calculated the $BAF_{fish}$ value for lead as a geometric mean of data from various literature sources described in U.S. EPA (1998). We don't expect Elemental mercury to deposit significantly onto soils and surface water; therefore, assume no transfer of elemental mercury to fish. Assume that all mercury in fish exists or is converted to the methyl mercury (organic) form after uptake into the fish tissue. For this HHRAP, we use the $BAF_{fish}$ value for methyl mercury listed in U.S. EPA (1997) for a trophic level 4 fish.<br><br>The following uncertainty is associated with this variable:<br>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.

This document recommends using *BAF*s 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.

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 $K_{ow}$ greater than 4.0 but less than 6.5 should be calculated from the following references for the limetic ecosystem and the literal 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.

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. "*Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions*." Update to EPA/600/6-90/003. Office of Research and Development, National Center for Environmental Assessment, U.S. EPA. EPA/600/R-98/137. December.

U.S. EPA. 1999. *Screening Level Ecological Risk Assessment Protocol for Hazardous Waste Combustion Facilities.* Peer Review Draft. Office of Solid Waste. August.

**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 significantly 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**<br>This variable is COPC- and site-specific, and is calculated using the equation in Table B-4-25.<br><br>Uncertainties associated with this variable include the following:<br>(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. We expect the degree of uncertainty associated with variables $\theta_{bs}$, *TSS*, $d_{wc}$, and $d_{bs}$ to be limited either because the probable ranges for these variables are narrow or information allowing reasonable estimates is generally available.<br>(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 | **0.03 to 0.07**<br>We recommend this default range of values to be representative of warm water non-salmonoid fish (3 percent lipid content) at the low end and cold water salmonoid game fish at the high end (7 percent lipid content). Examples of non-salmonoid fish that may have lipid percentages in the edible portion at the lower end of the range would be catfish, northern pike, and walleye. U.S. EPA (1994a) and U.S. EPA (1994b) recommended values of 7 percent, which was originally cited by Cook et al. (1991). A value of 3 percent lipid content for the edible portion is provided by U.S. EPA (2000).<br><br>The following uncertainty is associated with this variable:<br>(1) Lipid content may vary between different species of fish. Therefore, using a default $f_{lis}$ value may result in under- or overestimating $C_{fish}$. |
| *BSAF* | Biota-to-sediment accumulation factor | unitless<br><br>([mg COPC/kg lipid tissue]/[mg COPC/kg sediment]) | **Varies**<br>This variable is COPC-specific. We discuss this variable in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database.<br><br>These factors are applied only to PCDDs, PCDFs, and polychlorinated biphenyls (PCBs), consistent with NC DEHNR (1997), U.S. EPA (1992), U.S. EPA (1994), and U.S. EPA (1995).<br><br>Uncertainty is associated with this variable:<br>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, using *BSAFs* to estimate COPC accumulation in these species may be uncertain. |
| $OC_{sed}$ | Fraction of organic carbon in bottom sediment | unitless | **0.04**<br>This variable is site-specific. We recommend 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 (1994b) and NC DEHNR (1997) guidance.<br><br>The following uncertainty is associated with this variable::<br>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, we expect any uncertainty to be limited in most cases. |

## TABLE B-4-28

## 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) 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. 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.

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.

U.S. EPA. 2000. *Draft Methodology for Deriving Ambient Water Quality Criteria for Protection of Human Health. Technical Support Document Volume III: Bioaccumulation Part 1 - Development of National Bioaccumulation Factors.* Office of Science and Technology in the Office of Water.

This document is cited as one of the reference source documents for the fish lipid content value.

**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).

$$C_{a(Hg^0)} = 0.002\, Q_{(Total)} \cdot \left[F_{v(Hg^0)} \cdot Cyv + (1.0 - F_{v(Hg^0)}) \cdot Cyp\right]$$

$$C_{a(Hg^{2+})} = 0.48 Q_{(Total)} \cdot \left[F_{v(Hg^{2+})} \cdot Cyv + (1.0 - F_{v(Hg^{2+})}) \cdot Cyp\right]$$

| Variable | Description | Units | Value |
|---|---|---|---|
| $C_a$ | Air concentration | µg/m$^3$ | |
| $Q$ | COPC-specific emission rate | g/s | **Varies**<br>This variable is COPC- and site-specific. See Chapters 2 and 3 for guidance on calculating 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**<br>This variable is COPC-specific. We discuss $F_v$ in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database. This range is based on values presented in Appendix A-2. Values are also presented in U.S. EPA (1994b) and NC DEHNR (1997).<br><br>$F_v$ 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).<br><br>The following uncertainties are associated with this variable:<br>(1) It uses 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, using 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.<br>(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**<br>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**<br>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)

## (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: 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)**

**(Page 1 of 3)**

**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 calculating $F_v$, 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, using 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)

$$C_{acute} = Q \cdot \left[F_v \cdot Chv + (1.0 - F_v) \cdot Chp\right]$$

Consistent with Table B-5-1, 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 ($Hg^{2+}$). Although calculated as separate species, acute toxicity benchmarks are not available for mercury and therefore, acute air concentration for each species should be summed for comparison to the acute toxicity benchmark for mercury.

$$C_{acute(Hg^0)} = 0.002\, Q_{(Total)} \cdot \left[F_{v(Hg^0)} \cdot Chv + (1.0 - F_{v(Hg^0)}) \cdot Chp\right]$$

$$C_{acute(Hg^{2+})} = 0.48\, Q_{(Total)} \cdot \left[F_{v(Hg^{2+})} \cdot Chv + (1.0 - F_{v(Hg^{2+})}) \cdot Chp\right]$$

| Variable | Description | Units | Value |
|---|---|---|---|
| $C_{acute}$ | Acute air concentration | µg/m$^3$ | |
| $Q$ | COPC-specific emission rate | g/s | **Varies**<br>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)**

**(Page 2 of 3)**

| Variable | Description | Units | Value |
|---|---|---|---|
| $F_v$ | Fraction of COPC air concentration in vapor phase | unitless | **0 to 1**<br>This variable is COPC-specific. We discuss $F_v$ in detail in Appendix A-2, and offer COPC-specific values in the HHRAP companion database. This range is based on values presented in Appendix A-2. Values are also presented in U.S. EPA (1994b) and NC DEHNR (1997).<br><br>$F_v$ 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).<br><br>The following uncertainties are associated with this variable:<br>(1) It 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, using 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.<br>(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 | µg-s/g-m$^3$ | **Varies**<br>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 | µg-s/g-m$^3$ | **Varies**<br>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. |

**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.