



## Appendix I-D Ecological Risk

Whereas Section 4.2 presents the methodology and key results of the screening assessment of risk to the environment, this appendix provides the details of the input and output of the assessment. Much of the information in this appendix is provided on diskette. Two of the files on diskette are very large. To make them available, they have been compressed with the commercial compression routine PKZIP (PKWARE 1992). "Exe" as the extension of the file name indicates the files that have been compressed and that can decompress themselves. When these files are decompressed, they will automatically reestablish the computer code and necessary input files.

To decompress an "exe" file, do the following:

- ◆ Create a directory and copy the "exe" files into it from the diskette.
- ◆ To decompress the files:
  - In DOS, while in the directory you created, type the "exe" file name and hit "enter".
  - In Microsoft Windows File Manager, double click on each "exe" file and it will decompress. To view the decompressed file names in File Manager, click on REFRESH under WINDOW.
  - In Microsoft Windows 95, click on START, then RUN, then BROWSE; indicate directory you have created; double click on each "exe" file to decompress it.
- ◆ To view the individual files, open the files in any text processing software or spreadsheet.

This appendix provides information on the following:

- ◆ measurement endpoint values used in the risk assessment
- ◆ exposure model description and parameters
- ◆ calibration parameters for copper and zinc
- ◆ environmental hazard quotients
- ◆ risk categories from stochastic modeling

### Measurement Endpoint Values Used in the Risk Assessment

A Microsoft Excel file ("meas-end.xls") on diskette lists the benchmark species and toxicological responses used in determining toxicological values for the species of interest. The file identifies the species, contaminants, LD<sub>50</sub> and LOEL values, surrogate species used if there was one, and the sources of information.



## Exposure Model Description and Parameters

The following description represents a compilation of exposure formulas that were primarily derived from EPA's wildlife exposure factors handbook (EPA 1993). The parameters used in the formulas are in a Microsoft Excel file ("paramtrs.xls") on diskette.

### Air-Respiring or Transpiring Species

#### Plants

##### Rain Splash

$$C_{\text{par}} = EC_{\text{soil}} * K_{\text{ps1}} \text{ (Hope 1995)}$$

where

$C_{\text{par}}$  = equilibrium concentration in above-ground plant parts from rain splash ( $\mu\text{g}/\text{kg}$  or  $\mu\text{Ci}/\text{kg}$  wet)

$EC_{\text{soil}}$  = concentration in surface soil (about top 1 cm) ( $\mu\text{g}/\text{kg}$  or  $\mu\text{Ci}/\text{kg}$  dry)

$K_{\text{ps1}}$  = plant-soil partition coefficient for rain splash on fresh-weight basis (kg soil/kg plant wet weight)

##### Calibration

$K_{\text{ps1}}$  = 0.0034, coefficient of variation = 1 (McKone 1993)

$EC_{\text{soil}}$  = measured concentration from database or estimated from equilibrium with groundwater

**Root Uptake to Above-Ground Plant Tissue.** The equation below was modified from Hope (1995). One of the terms in parentheses would be used depending on whether the contaminant was organic ( $K_{\text{ps2}}$ ) or inorganic [ $B_v(1-f_w)$ ].

$$C_{\text{pau}} = EC_{\text{soil}} * [K_{\text{ps2}}, B_v(1-f_w)]$$

where

$C_{\text{pau}}$  = equilibrium concentration in above-ground plant parts from root uptake ( $\mu\text{g}/\text{kg}$  or  $\mu\text{Ci}/\text{kg}$  wet)

$K_{\text{ps2}}$  = plant-soil partition coefficient for root-zone soil to above-ground plant parts for organic contaminants - fresh weight basis (kg soil/kg plant wet weight)

$B_v$  = bioconcentration factor for vegetative plant parts for inorganic contaminants - dry weight basis (unitless)

$f_w$  = weight fraction of plant tissue that is water (unitless)

**Submodel.** In the equation below the regression model was reported in McKone (1993). The coefficient of variation equals 4.

$$K_{\text{ps2}} = 7.7 * K_{\text{ow}}^{-0.58}$$



where

$K_{ow}$  = octanol-water partition coefficient

### **Calibration**

$B_v$  = see "paramtrs.xls" file on diskette

$f_w$  from Spector (1956), Martin et al. (1951, p. 12) and EPA (1993, p. 4-14)

$K_{ow}$  from MEPAS chemical database (Streng and Peterson 1989)

**Special Case for Tritium (Hydrogen-3).**  $B_v$  in the model above incorporates field- or experiment-derived conversion of sediment-bound contaminants into a pore-water phase, the primary phase for uptake of metals (Kabata-Pendias and Pendias 1984). This conversion is problematic for tritium because it is carried entirely in the water phase ( $K_d = 0$ ). Plants take up tritium from groundwater and pore water (for example, Rickard and Price 1989) at a concentration ratio of somewhat less than 1 (Driver 1994). Consequently, the present model was set up to use a  $B_{\text{porewater}}$  value for tritium of 0.9, which was multiplied by the pore water (in other words, groundwater) concentration to obtain an equilibrium plant concentration.

### **Foliar Uptake from Soil by Vapor**

$$C_{\text{pav}} = EC_{\text{vap}} * K_{\text{pa1}} \text{ (Hope 1995)}$$

where

$C_{\text{pav}}$  = equilibrium concentration in above-ground plant parts from vapor uptake ( $\mu\text{g}/\text{kg}$  or  $\mu\text{Ci}/\text{kg}$  wet)

$EC_{\text{vap}}$  = concentration of gas-phase contaminant ( $\mu\text{g}$  or  $\mu\text{Ci}/\text{m}^3$ )

$K_{\text{pa1}}$  = plant-air partition coefficient for air to above-ground plant parts for organic contaminants ( $\text{m}^3/\text{kg}$  wet weight)

### **Submodel: $K_{\text{pa1}}$**

$$K_{\text{pa1}} = (f_{\text{pa}} + (f_{\text{pw}} + f_{\text{pl}} * K_{\text{ow}}) * (R * T)/H) * (1/\rho_p)$$

(Reiderer 1990, coefficient of variation = 14, McKone 1993)

where

$f_{\text{pa}}$  = volume fraction of plant tissue in air (unitless)

$f_{\text{pw}}$  = volume fraction of plant tissue that is water (unitless)

$f_{\text{pl}}$  = volume fraction of plant tissue that is lipid (unitless)

$R$  = universal gas constant ( $\text{Pa}\cdot\text{m}^3/\text{mol}\cdot\text{K}$ )

$T$  = temperature (K)

$H$  = contaminant-specific Henry's law constant ( $\text{Pa}\cdot\text{m}^3/\text{mol}$ )

$\rho_p$  = plant tissue density ( $\text{kg}/\text{m}^3$ )

**Submodel:  $EC_{vap}$** 

$$EC_{vap} = EC_{soil} * 1 / \{ (LS * V * Dh) / A * [(3.14 * \zeta * I)^{0.5} / (2 * D_{ei} * E * K_{as} * 10^{-3} \text{ kg/g})] \} \text{ (EPA 1991)}$$

LS = length of side of contaminated area (m)

V = wind speed in mixing zone (m/s)

Dh = diffusion height (m)

A = area of contamination ( $\text{cm}^2$ )

$\zeta$  = effective diffusion rate ( $\text{cm}^2/\text{s}$ )

I = exposure interval (s)

$D_{ei}$  = effective diffusivity ( $\text{cm}^2/\text{s}$ )

E = soil porosity (unitless)

$K_{as}$  = soil/air partition coefficient ( $\text{g soil}/\text{cm}^3 \text{ air}$ )

**Submodel:  $\zeta$** 

$$\zeta = (D_{ei} * E) / (E + (\rho_s * (1-E) / K_{as}))$$

$\rho_s$  = soil density ( $\text{g}/\text{cm}^3$ )

**Submodel:  $K_{as}$** 

$$K_{as} = (H * 41) / (K_d * 1.0125E5 \text{ Pa/atm}) \text{ (EPA 1991)}$$

where

41 = units conversion factor

$K_d$  = soil-water partition coefficient ( $\text{cm}^3/\text{g}$ )

**Submodel:  $K_d$** 

$$K_d = 0.62 * K_{ow} * f_{oc} \text{ (regression model in Nicholls 1991)}$$

$f_{oc}$  = soil organic carbon content (unitless)

**Submodel:  $D_{ei}$** 

$$D_{ei} = D_i * E^{0.33} \text{ (EPA 1991)}$$

where

$D_i$  = molecular diffusivity ( $\text{cm}^2/\text{s}$ )

**Calibration**

$$f_{pa} = 0.5 \text{ (McKone 1993)}$$

$$f_{pw} = 0.4 \text{ (McKone 1993)}$$

$$f_{pl} = 0.01 \text{ (McKone 1993)}$$

$$R = 8.314$$



- $T = 285$  K default Hanford average (Stone et al. 1983)  
 $H =$  from MEPAS database (Streng and Peterson 1989)  
 $\rho_p = 1000$  (McKone 1993)  
 $\rho_s =$  for sediment or 2.65 default (EPA 1991)  
 $E = 0.35$  default  
 $\rho_a = 0.05$   
 $f_{oc} =$  from segment or 0.01 default  
 $K_{ow} =$  from MEPAS database  
 $LS = 1000$  m  
 $V = 2.68$  m/s default Hanford average @ 2.1 meters (7 feet) (Stone et al. 1983)  
 $Dh =$  Average distance from ground to middle of foliage (fungi: 0.05 m, grasses/forbs: 0.1 m, trees: 5 m)  
 $A = 50$  cm \*  $LS * 100$  cm/m  
 $D_i =$  chemical-specific from MEPAS database  
 $I = 3.1536 * 10^7$  sec default (1 year)

### Foliar Adsorption of Particulates from Soil

$$C_{pap} = EC_{par} * K_{pa2} \text{ (Hope 1995)}$$

where

- $C_{pap} =$  equilibrium concentration in above-ground plant parts from particulate adsorption ( $\mu\text{g}/\text{kg}$  or  $\mu\text{Ci}/\text{kg}$  wet)  
 $EC_{par} =$  air concentration of particulate-bound contaminant ( $\mu\text{g}$  or  $\mu\text{Ci}/\text{m}^3$ )  
 $K_{pa2} =$  plant-air partition coefficient for air to above-ground plant parts for particulate-bound contaminants ( $\text{m}^3/\text{kg}$  wet weight)

#### *Submodel: $EC_{par}$*

$$EC_{p\_air} = EC_{soil}/PEF \text{ (EPA 1991)}$$

where

- PEF = particulate emission factor ( $\text{m}^3/\text{kg}$ )

#### *Submodel: PEF*

$$PEF = (LS * V * Dh * 3600 \text{ s/hr}/A/10,000 \text{ cm}^2/\text{m}^2) * (1000 \text{ g}/\text{kg} (Rf * (1-G) * (U_m/U_t)^3 * F(x)))$$

(EPA 1991)

where

- $Rf =$  respirable fraction ( $\text{g}/\text{m}^2\text{-hr}$ )  
 $G =$  fraction of vegetative cover (unitless)  
 $U_m =$  mean annual wind speed (m/s)  
 $U_t =$  erosion threshold wind speed at 10 m (m/s)  
 $F(x) =$  Cowherd et al. (1985) function (unitless)

**Submodel:  $U_t$** 

$$U_t = \text{TFV} * \ln(10 \text{ m/SRH})/0.4 \text{ (Cowherd et al. 1985)}$$

where

TFV = threshold friction velocity (m/s)

SRH = surface roughness height (m)

**Submodel: TFV**

$$\text{TFV} = \text{NECF} * (64 + 0.0055 * \text{APSD} * 1000)/100 \text{ (regression model in Cowherd et al. 1985)}$$

where

NECF = non-erodible elements correction factor (unitless)

APSD = aggregate particle size distribution (mm)

**Calibration**

$K_{pa2}$  = 3300 (coefficient of variation = 1.5, McKone 1993)

Rf = 0.036 (EPA 1991)

$U_m$  = 3.44 m/s (Stone et al. 1983)

SRL = 0.018 m (grass - Jørgensen et al. 1991, p. 230)

NECF = 0

APSD = 0.04 mm (coarse silt size - Gee and Bauder 1986, p. 384)

G = 0.5

F(x) = 0.0497 (EPA 1991)

**Total Plant Burden**

$$\text{Internal burden: } C_{\text{pai}} = C_{\text{pav}} + C_{\text{pau}}$$

where

$C_{\text{pai}}$  = equilibrium tissue concentration of contaminants (( $\mu\text{g}$  or  $\mu\text{Ci}$ /kg tissue)

(Note this derivation assumes that none of the adsorbed contaminant enters the plant.)

$$\text{Total burden (as eaten by herbivore): } C_{\text{pat}} = C_{\text{par}} + C_{\text{pap}} + C_{\text{pai}}$$

where

$C_{\text{pat}}$  = equilibrium concentration of contaminants in and on plant tissue ( $\mu\text{g}$  or  $\mu\text{Ci}$ /kg tissue)



## Terrestrial Animals

### Dermal Contact - Sediment

$$C_{dersi} = D_{dersi}/K_{ei} \text{ (from Hope 1995)}$$

where

$C_{dersi}$  = equilibrium contaminant body burden in species  $i$  from dermal contact with soil ( $\mu\text{g}/\text{kg}$  or  $\mu\text{Ci}/\text{kg}$  body weight)

$D_{dersi}$  = absorbed daily dose for species  $i$  from dermal contact with soil ( $\mu\text{g}/\text{kg}$  or  $\mu\text{Ci}/\text{kg}/\text{day}$ )

$K_{ei}$  = contaminant-specific depuration rate for species  $i$  (1/day)

#### *Submodel: $D_{ders}$*

$$D_{ders} = [(SA_i * P_{csi} * S_{ai} * EC_{soil} * CF * \delta_i/W_i] * \theta_i * \iota_i \text{ (modified from EPA 1991)}$$

where

$SA_i$  = surface area of species  $i$  ( $\text{cm}^2$ )

$P_{csi}$  = fraction of surface area of species  $i$  in contact with soil per day (1/day)

$S_{ai}$  = skin adherence factor for species  $i$  ( $\text{mg}/\text{cm}^2$ )

$CF$  = conversion factor ( $10^{-6} \text{ kg}/\text{mg}$ )

$\delta_i$  = contaminant-specific dermal absorption factor for species  $i$  (unitless)

$W_i$  = body weight of species  $i$  (kg wet weight)

$\theta_i$  = area use factor for species  $i$  (ratio of contaminant area to home range - unitless)

$\iota_i$  = seasonality factor for species  $i$  (fraction of year spent at the contaminated site - unitless)

#### *Submodel: $SA_i$*

$$\text{Birds: } SA_i = 10 * (W_i * 1000 \text{ g}/\text{kg})^{0.667} \text{ (EPA 1993)}$$

$$\text{Mammals: } SA_i = 12.3 * (W_i * 1000)^{0.65} \text{ (EPA 1993)}$$

$$\text{Woodhouse's toads: } SA_i = 0.953 * (W_i * 1000)^{0.725} \text{ (EPA 1993)}$$

$$\text{Lizards: } SA_i = 8.42 * (W_i * 1000)^{0.694} \text{ (EPA 1993 - salamander applied to lizards)}$$

$$\text{Western aquatic garter snake: } = 2 * \pi * 1 \text{ cm radius (1 cm + 106 cm length)} \\ \text{(EPA 1993; Stebbins 1985)}$$

$$\text{Terrestrial arthropods: } = 0.0002 \text{ cm}^2$$

#### *Calibration*

$\delta_i$  = see "paramtrs.xls" on diskette

$K_{ei}$  = see "paramtrs.xls" on diskette

$P_{CS}$  = mammal: 0.22 (Maughan 1993); other vertebrates: 0.25, arthropods: 1

$W_i$  = for species using Silva and Downing (1995); Dunning (1993); EPA (1993); Nagy (1983)

$S_{ai}$  = 1.45 (EPA 1991)

$\theta_i$  = 1



$\iota_i = 1$  for all species except common snipe (0.33), bufflehead (0.5), Forster's tern (0.5), cliff swallow (0.5), and bald eagle (0.5) (Ennor 1991)

**Dermal Contact - Water**

$$C_{derwi} = D_{derwi}/K_{ei} \text{ (Hope 1995)}$$

where

$C_{derwi}$  = equilibrium contaminant body burden for species  $i$  from dermal contact with water ( $\mu\text{g}$  or  $\mu\text{Ci}/\text{kg}$  body weight)

$D_{derwi}$  = absorbed daily dose for species  $i$  from dermal contact with water ( $\mu\text{g}$  or  $\mu\text{Ci}/\text{kg}\text{-day}$ )

**Submodel:  $D_{derw}$**

$$D_{derwi} = [(SA_i * P_{cwi} * ET_i * EC_{surface} * CF * K_{pi})/W_i] * \theta_i * \iota_i$$

(modified from EPA 1991 to include use and seasonality factors)

where

- $SA_i$  = surface area of species  $i$  ( $\text{cm}^2$ )
- $P_{cwi}$  = fraction of surface area of species  $i$  available for contact with water (unitless)
- $ET_{wi}$  = average exposure time to water per day for species  $i$  (hr/day)
- $EC_{surface}$  = concentration in surface water ( $\mu\text{g}/\text{L}$  or  $\mu\text{Ci}/\text{L}$ )
- $CF$  = volumetric conversion factor for water ( $1 \text{ L}/1000 \text{ cm}^3$ )
- $K_{pi}$  = contaminant-specific dermal absorption factor for species  $i$  from water ( $\text{cm}/\text{hr}$ )
- $W_i$  = body weight of species  $i$  (kg wet weight)
- $\theta_i$  = area use factor for species  $i$  (ratio of contaminant area to home range - unitless)
- $\iota_i$  = seasonality factor for species  $i$  (fraction of year spent at the contaminated site - unitless)

**Calibration**

$K_{pi}$  = See "paramtrs.xls" file on diskette  
 ET and  $P_{cwi}$  (EPA 1993):

Species	$ET_i$	$P_{cwi}$
Woodhouse's toad	20	1
Western aquatic garter snake	12	1
Beaver, muskrat	20	1
Mule deer	1	0.8
Raccoon	2	0.1
Terrestrial arthropods, lizards, coyote, weasel, western harvest mouse, California quail, cliff swallow, northern harrier, American kestrel	0	0
Bald eagle	2	0.8
Forster's tern	8	0.5
Great blue heron	20	0.1
Other waterfowl	20	0.5



**Total Dermal Dose.** Equilibrium body burden from dermal exposure:

$$C_{\text{deri}} = C_{\text{dersi}} + C_{\text{derwi}}$$

where

$C_{\text{deri}}$  = total equilibrium body burden from dermal exposure for species  $i$  ( $\mu\text{g}$  or  $\mu\text{Ci}/\text{kg}$  body weight)

Absorbed dose:

$$D_{\text{deri}} = D_{\text{dersi}} + D_{\text{derwi}}$$

where

$D_{\text{deri}}$  = total daily dermal absorbed dose for species  $i$  ( $\mu\text{g}$  or  $\mu\text{Ci}/\text{kg}$  body weight/day)

### Inhalation - Vapor

$$C_{\text{ivi}} = D_{\text{ivi}} * (\alpha_{\text{vapi}}/K_{\text{ei}}) \text{ (Hope 1995)}$$

where

$C_{\text{ivi}}$  = equilibrium contaminant body burden for species  $i$  from inhalation of vapor ( $\mu\text{g}/\text{kg}$  or  $\mu\text{Ci}/\text{kg}$ )

$D_{\text{ivi}}$  = applied daily dose to species  $i$  from vapor inhalation ( $\mu\text{g}/\text{kg}$  or  $\mu\text{Ci}/\text{kg}\text{-day}$ )

$\alpha_{\text{vapi}}$  = inhalation absorption factor for species  $i$  (unitless)

#### Submodel: $D_{\text{ivi}}$

$$D_{\text{ivi}} = [(\text{IR}_i * \text{EC}_{\text{vap}})/W_i] * \theta_i * \tau_i \text{ (modified from Hope (1995) using EPA (1993) calculation for } \text{EC}_{\text{vap}} \text{ as above)}$$

where

$\text{IR}_i$  = resting inhalation rate of species  $i$  ( $\text{m}^3/\text{day}$ ) and rest as above

#### Calibration

$\text{IR}_i$ :

Species	Resting IR	Correction Factor for Field IR	$\text{IR}_i$
Mammals	$= 0.5458 * W_i^{0.80}$ (EPA 1993)	2 (EPA 1993)	$2 * 0.5458 * W_i^{0.80}$
Birds	$= 0.4089 * W_i^{0.77}$ (EPA 1993)	2 (EPA 1993)	$2 * 0.4089 * W_i^{0.77}$
Woodhouse's toad	see below	2 (EPA 1993)	$5.8 * 10^{-4}$
Lizards ( <i>Uta</i> ) and western aquatic garter snake	see below		$0.00045 * (W_i * 1000)^{0.8}$
Terrestrial arthropods	see below		$0.00045 * (W_i * 1000)^{0.8}$



**Woodhouse's toads.** EPA (1993) gives the resting metabolic rate of 74.8 g bullfrog adults at 5°C as 1-L O<sub>2</sub>/kg/d. Because gas exchange through the skin accounts for 18 percent of the O<sub>2</sub> uptake (EPA 1993), the respired intake fraction necessary to support the referenced metabolic demand is 0.82-L O<sub>2</sub> respired/kg/d. The fraction of O<sub>2</sub> in dry atmosphere is 20.95 percent (Schmidt-Nielson 1975, p. 8); thus the volume of respired air required to support the referenced metabolic rate is 0.82-L O<sub>2</sub>/0.2095-L O<sub>2</sub>/L air, or 3.914-L air/kg toad/d. Finally, multiplication of this result by a correction factor (1 m<sup>3</sup>/1000 L) and the weight of the toads (0.0748 kg) gives the resting calibrated value of 2.9 \* 10<sup>-4</sup> m<sup>3</sup>/d per toad, which is multiplied by 2 to provide a field-corrected inhalation rate of 5.8 \* 10<sup>-4</sup> m<sup>3</sup>/d per toad.

**Reptiles.** EPA (1993) cites the following formula for active field metabolic rate for adult lizards and snakes:

$$\text{MR (ml O}_2\text{/hr)} = 0.013 * (\text{W}_i * 1000)^{0.80} * 10^{0.038 * ^\circ\text{C}} * 10^{0.14}$$

Assuming these reptiles are in equilibrium with the average annual Hanford temperature (12°C - Stone et al. 1983), using the atmospheric composition of O<sub>2</sub> as above, and converting hours to days and milliliters to m<sup>3</sup> gives:

$$\text{IR (m}^3\text{/day)} = 10^{-6} \text{ m}^3\text{/ml} * 24 \text{ hr/day} * 1 \text{ ml air}/.2095 \text{ ml O}_2 * 0.013 \text{ ml O}_2\text{/hr} * (\text{W}_i * 1000)^{0.80} * 10^{0.00456} * 10^{0.14}$$

or

$$\text{IR}_i \text{ (m}^3\text{/day)} = 0.00045 * (\text{W}_i * 1000)^{0.80}$$

Terrestrial arthropods - inhalation treated as per reptiles.

$\alpha_{\text{vapi}}$  = see "paramtrs.xls" file on diskette

### Inhalation - Particulates

$$C_{\text{ipi}} = D_{\text{ipi}} * (\alpha_{\text{pari}}/K_{\text{ei}}) \text{ (Hope 1995)}$$

where

$C_{\text{ipi}}$  = equilibrium contaminant body burden for species i from inhalation of particulates ( $\mu\text{g/kg}$  or  $\mu\text{Ci/kg}$ )

$D_{\text{ipi}}$  = applied daily dose to species i from particulate inhalation ( $\mu\text{g/kg}$  or  $\mu\text{Ci/kg-day}$ )

$\alpha_{\text{pari}}$  = inhalation particulate absorption factor (unitless)

#### Submodel: $D_{\text{ipi}}$

$D_{\text{ipi}} = [(\text{IR}_i * \text{EC}_{\text{par}})/\text{W}_i] * \theta_i * \tau_i$  [modified from Hope (1995) using EPA (1993) calculation for  $\text{EC}_{\text{vap}}$  as above]



### Calibration

$\alpha_{\text{pari}}$  = see "paramtrs.xls" file on diskette

**Total Inhalation Dose.** Absorbed dose:

$$C_{\text{inhi}} = C_{\text{ivi}} + C_{\text{ipi}}$$

where

$C_{\text{inhi}}$  = total equilibrium burden from inhalation for species  $i$  ( $\mu\text{g}$  or  $\mu\text{Ci}$  / kg body weight)

Applied dose:

$$D_{\text{inhi}} = D_{\text{ivi}} + D_{\text{ipi}}$$

where

$D_{\text{inhi}}$  = total inhalation applied dose for species  $i$  ( $\mu\text{g}$  or  $\mu\text{Ci}/\text{kg}$  body weight/day)

### Ingestion - Water

$$C_{\text{ingwi}} = D_{\text{ingwi}} * (\alpha_{\text{ingi}}/K_{\text{ei}}) \text{ (after Hope 1995)}$$

where

$C_{\text{ingwi}}$  = equilibrium contaminant body burden for species  $i$  from ingestion of water ( $\mu\text{g}/\text{kg}$  or  $\mu\text{Ci}/\text{kg}$ )

$D_{\text{ingwi}}$  = applied daily dose to species  $i$  from water ingestion ( $\mu\text{g}/\text{kg}$  or  $\mu\text{Ci}/\text{kg}\text{-day}$ )

$\alpha_{\text{ingi}}$  = ingestion absorption factor for species  $i$  (unitless)

### Submodel: $D_{\text{ingwi}}$

$$D_{\text{ingwi}} = [(WI_i * EC_{\text{surface}} \text{ or } EC_{\text{springs}})/W_i] * \theta_i * \iota_i$$

[modified from EPA (1993) using site use fractions as above]

where

$WI_i$  = water ingestion rate of species  $i$  (L/day)

$EC_{\text{springs}}$  = concentration in spring/seep water, where present ( $\mu\text{g}/\text{L}$  or  $\mu\text{Ci}/\text{L}$ ), otherwise,  $EC_{\text{surface}}$  is used as the default

$EC_{\text{surface}}$  = concentration in surface water

### Calibration

$WI_i$ : (EPA 1993)

Species	$WI_i$
Mammals	$= 0.099 \times W_i^{0.90}$
Birds	$= 0.059 \times W_i^{0.67}$
Woodhouse's toad	0
Lizards ( <i>Uta</i> ) and western aquatic garter snake	0
Terr. arthropods	0

$\alpha_{\text{ing}}$  = see "paramtrs.xls" file on diskette

**Ingestion - Soil**

$$C_{\text{ingsi}} = D_{\text{ingsi}} * (\alpha_{\text{ingi}}/K_{\text{ci}}) \text{ (after Hope 1995)}$$

where

$C_{\text{ingsi}}$  = contaminant body burden to species i from ingestion of soil ( $\mu\text{g}/\text{kg}$  or  $\mu\text{Ci}/\text{kg}$  body weight)

$D_{\text{ingsi}}$  = applied daily dose to species i from soil ingestion ( $\mu\text{g}/\text{kg}$  or  $\mu\text{Ci}/\text{kg-day}$ )

$\alpha_{\text{ingi}}$  = ingestion absorption factor for species i (unitless)

**Submodel:  $D_{\text{ingsi}}$** 

$$D_{\text{ingsi}} = [(SI_i * NIR_{\text{totali}} * EC_{\text{surface}} * F_{\text{dwi}})] * \theta_i * \iota_i$$

[modified from EPA (1993) using site use fractions as above]

where

$SI_i$  = soil ingestion rate of species i (kg soil ingested/kg dry diet)

$NIR_{\text{totali}}$  = total normalized ingestion rate for species i (kg prey wet weight/kg predator body weight/day)

$F_{\text{dwi}}$  = conversion factor, dry diet to wet diet for species i (kg dry/kg wet)

**Submodel:  $NIR_{\text{totali}}$** 

$$NIR_{\text{totali}} = FMR_i / (\sum (P_{ij} * ME_j) * W_i)$$

(EPA 1993, equations 4-11 and 4-12)

where

$FMR_i$  = free-living metabolic rate of predator (kcal/day)

$P_{ij}$  = wet weight or volume fraction of i's diet consisting of prey j (unitless)

$ME_j$  = metabolizable energy from prey j (kcal/kg prey wet wt)

**Submodel:  $FMR_i$** 

Birds:  $FMR_i = 3.12 * (W_i * 1000 \text{ g/kg})^{0.605}$  (EPA 1993)

Herbivorous mammals:  $FMR_i = 1.419 * (W_i * 1000 \text{ g/kg})^{0.727}$  (EPA 1993)

Non-herbivorous mammals:  $FMR_i = 0.6167 * (W_i * 1000 \text{ g/kg})^{0.862}$  (EPA 1993)

Rodents =  $2.514 * (W_i * 1000 \text{ g/kg})^{0.507}$  (EPA 1993)

Reptiles:  $FMR_i = 0.053 * (W_i * 1000 \text{ g/kg})^{0.799}$  (EPA 1993)

Woodhouse's toads:  $FMR_i = 0.000288 * (0.047 * (W_i * 10^6 \text{ mg/kg})^{1.06})^{0.878}$

(derived from EPA 1993 using tadpole FMR)

Terrestrial arthropods: as per reptiles

**Submodel:  $ME_j$** 

$$ME_j = (GE_j * AE_j) \text{ (EPA 1993)}$$



where

$GE_j$  = gross energy from prey  $j$  (kcal/kg wet weight)

$AE_j$  = assimilation efficiency of prey  $j$  (unitless)

### Calibration

$SI_i$ : (Beyer et al. 1994)

Species	$SI_i$
Mule deer	0.02
Raccoon, muskrat, beaver	0.09
Western harvest mouse	0.02
Coyote	0.09
Weasel	0.03
American coot, snipe	0.18
Mallard	0.033
Canada goose	0.08
Raptors and fish-eating birds	0.02 (average of fish-eating species)
California quail	0.09 (used value for wild turkey)
Cliff swallow	0.02 (lowest value of birds)
Woodhouse's toad	0.06 (see below)
Lizards ( <i>Uta</i> ), and western aquatic garter snake	0.054 (see below)
Terr. arthropods	0.054 (as per reptiles)

For Woodhouse's toad and reptiles,  $SI$  was estimated using the average of box (4.5%) and painted turtle (5.9%) estimates because of the lack of data for these groups (Beyer et al. 1994).

$F_{dw}$  =  $1 - \%H_2O = 0.17$  for all diets (average of fresh diets in EPA 1993, p. 4-14)

$P_{ij}$  = Species-specific values from Brandt et al. (1993), Johnsgard (1990), Zeiner et al. (1990), Ehrlich et al. (1988), Svendsen (1982), Dauble et al. (1980), Terres (1980), Fitzner and Schreckhise (1979), Fitzner and Rickard (1975), Becker (1973), Hanson and Browning (1956), Martin et al. (1951); see "paramtrs.xls" file on diskette

$GE_j$  = values for species groups from EPA (1993, p. 4-13-4-14) — Assigned values are shown below.

$AE_j$  = values were assigned to prey based on major taxon using EPA (1993, p. 4-15) — Data were averaged between avian and mammalian predators where both values were given. Assigned values are shown below.



Prey Group	Assigned GE <sub>i</sub>	Assigned AE <sub>i</sub>
Birds	1900	(0.78 + 0.84)/2 = 0.81
Mammals	1700	(0.78 + 0.84)/2 = 0.81
Reptiles	1400	0.81 (as per birds, mammals)
Amphibians	1200	0.81 (as per birds, mammals)
Fish	1200 (bony fish value)	(0.79 + 0.91)/2 = 0.85
Salmon adults	1600 (Halfon et al. 1996)	0.85
Salmon larvae	1400 (Halfon et al. 1996)	0.85
Rainbow trout adults	2100 (Halfon et al. 1996)	0.85
Rainbow trout larvae	1500 (Halfon et al. 1996)	0.85
Terrestrial insects	1600 (average of insects)	(0.72 + 0.87)/2 = 0.80
Crayfish	1100 (shrimp value)	0.77
Insect larvae	1200	0.77
<i>Daphnia</i>	740 (cladoceran value)	0.77
<i>Hyalella</i>	1100 (amphipod value)	0.77
Tadpoles	1200 (as per amphibians)	0.77
Molluscs	800 (bivalves sans shells)	0.77
Periphyton, phytoplankton	510	0.23
Macrophytes	520	0.23
Emergent vegetation (tule, Columbia yellowcress)	1600	0.39
Reed canarygrass, sedges, rushes	1300	0.47 (as per leaves and grasses)
Black cottonwood, mulberry	3200 (stems and twigs, 25% water)	0.34 (as per stems, twigs)
Fern, fungi	630 (as per dicot leaves)	0.73 (as per green forb)

### Ingestion - Food

$$C_{\text{ingfi}} = D_{\text{ingfi}} * (\alpha_{\text{ingfi}}/K_{\text{ei}}) \text{ (after Hope 1995)}$$

where

$C_{\text{ingfi}}$  = equilibrium body burden for species i from ingestion of food ( $\mu\text{g}/\text{kg}$  or  $\mu\text{Ci}/\text{kg}$  body weight)

$D_{\text{ingfi}}$  = applied daily dose to species i from food ingestion ( $\mu\text{g}/\text{kg}$  or  $\mu\text{Ci}/\text{kg} - \text{day}$ )

#### Submodel: $D_{\text{ingfi}}$

$$D_{\text{ingfi}} = \Sigma(C_j * \text{NIR}_j) * \theta_i * \nu_i \text{ [modified from Hope (1995) using EPA (1993)]}$$

where

$C_j$  = average contaminant concentration in jth food item ( $\mu\text{g}/\text{kg}$  or  $\mu\text{Ci}/\text{kg}$  wet weight)

$\text{NIR}_j$  = normalized ingestion rate of jth food type on a wet-weight basis (kg prey/kg body weight predator/day)



**Submodel:  $NIR_j$**

$$NIR_j = P_{ij} \times NIR_{totali} \text{ (EPA 1993, equation 4-10)}$$

**Calibration:  $C_j$ .** Plant prey:

$$C_j = C_{pat}$$

Animal prey:

$$C_j = C_{ingf} + C_{ings} + C_{ingw} + C_{inh} + C_{der}$$

**Total Ingestion Dose.** Applied daily dose:

$$D_{ingi} = D_{ingfi} + D_{ingsi} + D_{ingwi}$$

where

$$D_{ingi} = \text{applied daily dose for species } i \text{ from ingestion } (\mu\text{g/kg or } \mu\text{Ci/kg} \cdot \text{day})$$

Absorbed dose:

$$C_i = C_{ingfi} + C_{ingsi} + C_{ingwi} + C_{inhi} + C_{deri}$$

where

$$C_i = \text{equilibrium body burden for species } i \text{ from ingestion } (\mu\text{g/kg or } \mu\text{Ci/kg body weight})$$

## Water-Respiring or Transpiring Species

The basic models used in the screening assessment for estimating exposures of aquatic organisms to metal or organic contaminants in sediments, pore water, surface water, and the subsequent transfer through the food chain consist of mass-balance equilibrium models originally derived by R.V. Thomann and coworkers (Thomann et al. 1995, 1992; Thomann 1989). The basic equilibrium models presented in these papers were further modified by the authors to provide a system of equations generally applicable when only sediment data are available. The essential assumption used in that modification is that the aquatic system is not depleting contaminants, such that the three abiotic compartments (sediment, pore water, and surface water) are in static equilibrium (Thomann et al. 1992). This assumption may only be valid for large lacustrine systems. Clearly, it is invalid for the Columbia River. However, the basic models may be used directly with only minor modification to address the Columbia River system.

### Derivation of Dose

The basic equation for contaminant mass balance in an organism  $i$  feeding on prey  $j$  (including sediment) is given by:

$$dV_i/dt = k_{ui} (b_{pore} * EC_{pore} + b_{surface} * EC_{surface}) + \sum (P_{ij} * \alpha_{ij} * I_{ij} * V_j) - (K_i + G_i)V_i$$

(after Thomann et al. 1995, 1992)



where

- $V_i$  = body burden in predator species i (metals:  $\mu\text{g}$  or  $\mu\text{Ci}/\text{kg}$  dry weight - Thomann et al. 1995; organics:  $\mu\text{g}$  or  $\mu\text{Ci}/\text{g}$  lipid - Thomann et al. 1992)
- $V_j$  = body burden in prey species j (metals:  $\mu\text{g}$  or  $\mu\text{Ci}/\text{kg}$  dry weight - Thomann et al. 1995; organics:  $\mu\text{g}$  or  $\mu\text{Ci}/\text{g}$  lipid - Thomann et al. 1992) or in sediment (metals:  $\mu\text{g}$  or  $\mu\text{Ci}/\text{kg}$  dry sediment - Thomann et al. 1995; organics:  $\mu\text{g}$  or  $\mu\text{Ci}/\text{g}$  organic carbon - Thomann et al. 1992)
- $k_{ui}$  = contaminant uptake from dissolved sources for species i (metals:  $\text{L}/\text{g}$  dry weight/day - Thomann et al. 1995; organics:  $\text{L}/\text{g}$  lipid/day - Thomann et al. 1992)
- $b_{\text{pore}}$  = relative exposure to pore water (unitless)
- $b_{\text{surface}}$  = relative exposure to surface water ( $b_{\text{surface}} = 1 - b_{\text{pore}}$ ) (unitless)
- $EC_{\text{pore}}$  = contaminant concentration in pore water ( $\mu\text{g}/\text{L}$  or  $\mu\text{Ci}/\text{L}$ )
- $EC_{\text{surface}}$  = contaminant concentration in surface water ( $\mu\text{g}/\text{L}$  or  $\mu\text{Ci}/\text{L}$ )
- $P_{ij}$  = preference for consumption of food item j, including sediment as a separate prey item (unitless)
- $\alpha_{ij}$  = chemical assimilation efficiency for contaminant consumed along with prey j (g contaminant assimilated/g contaminant ingested)
- $I_{ij}$  = feeding rate of species i on prey item j (organic model: g prey lipid/g predator lipid/day, metal model: g prey dry weight/g predator dry weight/day) or on sediment (organic model: g organic carbon ingested/g predator lipid/day; metal model: g sediment dry weight/g predator dry weight/day)
- $K_i$  = loss rate of contaminant for species i, including depuration and metabolism (1/day)
- $G_i$  = growth rate of species i (1/day)

At steady state,  $dV_i/dt = 0$ , and the above equation reduces to:

$$V_i = [k_{ui} (b_{\text{pore}} * EC_{\text{pore}} + b_{\text{surface}} * EC_{\text{surface}}) + \sum (P_{ij} * \alpha_{ij} * I_{ij} * V_j)] / (K_i + G_i)$$

This form is used directly by Thomann et al. (1992) for analyzing body burdens of organic contaminants in aquatic species. To analyze body burdens of metals in aquatic species, Thomann et al. (1995) condense this analysis further, using the fact that  $k_{ui}/(K_i + G_i) = BCF_i$ , which is the contaminant-specific bioconcentration factor reflecting uptake directly from the surrounding aqueous medium. This gives the following equation:

$$V_i = BCF * (b_{\text{pore}} * EC_{\text{pore}} + b_{\text{surface}} * EC_{\text{surface}}) + \sum (P_{ij} * \alpha_{ij} * I_{ij} * V_j) / (K_i + G_i)$$

As given, the two equations return body burden estimates in units that differ between metals and organics. Further, the units are not comparable to those used in the in-air species exposure model (see previous section). Instead, the  $V_i$  must be converted to  $\mu\text{g}/\text{kg}$  wet weight (or  $\text{pCi}/\text{kg}$  wet weight for radionuclide contaminants). To accomplish that conversion, the following are applied:

$$\begin{aligned} \text{Metals: } C_i &= V_i / \text{awd}_i \\ \text{Organics: } C_i &= V_i * 1000 \text{ g/kg} * f_{Li} \end{aligned}$$



where

$$\begin{aligned} \text{awd}_i &= \text{wet-to-dry weight ratio for species } i \text{ (g wet/g dry)} \\ f_{Li} &= \text{fraction lipid in species } i \text{ (g lipid/g wet)} \end{aligned}$$

and  $C_i$  is as per in-air species given earlier.

It is these  $C_i$ 's that are used as input into the in-air model as body burdens of aquatic prey for in-air species such as coyote and bufflehead.

### Submodel: $K_{ei}$ for Organic Contaminants

$$K_i = (k_{ui}/K_{ow}/1000 \text{ g/L}) + K_{mi} \text{ (Thomann 1989)}$$

where

$$K_{mi} = \text{chemical loss rate in species } i \text{ due to metabolism and fecal loss (1/day)}$$

### Submodel: $G_i$

$$G_i = \delta * w_i^{-\beta} \text{ (Thomann et al. 1992)}$$

where

$\delta$  and  $\beta$  are regression parameters

### Submodel: $I_{ij}$

**For Intake of Organic Contaminants from Prey.** For biotic prey:

$$I_{ij} = ((G_i + \rho_i)/a_i) * (\text{awd}_j/\text{awd}_i) * (f_{Lj}/f_{Li}) * (f_{oci} f_{ocj}) \text{ (Thomann et al. 1992)}$$

where

$$\rho_i = \text{oxygen respiration rate for species } i \text{ (g O}_2\text{/g lipid/day)}$$

$$a_i = \text{organic carbon assimilation rate for species } i \text{ (g organic carbon assimilated/g organic carbon ingested)}$$

$$f_{oci} = \text{fraction organic carbon in species } i \text{ (g organic carbon/g dry weight)}$$

**For Intake of Metals/Radionuclides from Prey.** The above equation return values with units of g prey lipid/g predator lipid/day. The equivalent units for the metal uptake model of Thomann et al. (1995) are g prey dry weight/g predator dry weight/day. To evaluate metal and radionuclide uptake in aquatic systems, the following conversion was applied to produce consumption rates in the correct units:

$$\text{prey: } I_{\text{metal}} = I_{\text{organic}} * \text{awd}_j * f_{Lj}/\text{awd}_j/f_{Lj} = ((G_i + \rho_i)/a_i) * (f_{oci}/f_{ocj})$$

### For Intake of Contaminants from Sediment Ingestion

Thomann et al. (1995, 1992) estimate sediment ingestion as a purposeful portion of the organism's diet, meaning the organism searches for and consumes the sediment as a carbon source for food. This is a



valid assumption for species that consume sediment as the primary portion of their diet. None of the species identified for the screening assessment include sediment feeders. Instead, sediment intake can be more reasonably viewed as an incidental result of feeding on benthic organisms.

Using this assumption, sediment intake can be expressed as

$$\text{BAF}_{\text{ised}} = [\text{P}_{\text{ised}} * \alpha_{\text{ised}} * \Sigma (\text{P}_{\text{ij}} * \alpha_{\text{ij}} * \text{I}_{\text{ij}})] / (\text{K}_i + \text{G}_i)$$

where the subscript “ised” refers to organism i feeding on sediment,  $\text{BAF}_{\text{ised}}$  refers to the sediment-to-predator bioaccumulation factor (Thomann et al. 1992), and the remainder of the variables are as previously defined.

#### Submodel: $k_{\text{ui}}$ for Organic Contaminants

$$k_{\text{ui}} = (2.67 \text{ g O}_2/\text{g C} * f_{\text{oci}} * \rho_i * E_c) / (\text{awd}_i * C_0 * f_{\text{Li}}) \text{ (Thomann 1989)}$$

where

- $w_i$  = wet body mass for species i (g)
- $E_c$  = chemical transfer efficiency (unitless)
- $C_0$  = oxygen concentration in the river (mg/L)

This parameter is not used in the model for metal uptake. Instead, the BCF relationship is used and BCFs are obtained from the literature, as described below.

#### Submodel: $\text{BCF}_i$ for Organic Contaminants

$$\text{BCF}_i = k_{\text{ui}} / (\text{K}_i + \text{G}_i) \text{ (by definition)}$$

#### Submodel: $\rho_i$

$$\rho_i = * w_i \text{ (Thomann 1989)}$$

where

and are regression parameters.

#### Calibration

$\text{BCF}_i$  = for organic contaminants, the submodels for  $k_{\text{ui}}$  and  $\text{BCF}_i$  were used; otherwise, BCF values were obtained from the literature using a L/kg dry weight basis (see paramtrs.xls file on diskette)

$E_0$  = 0.8 (Thomann et al. 1992)

$E_c$  = function of  $K_{\text{ow}}$  (see below - Thomann et al. 1992)



Log $K_{ow}$	$E_c$
2	0.02511886
2.5	0.04466836
3	0.07943282
3.5	0.14125375
4	0.25118864
4.5	0.8
5	0.8
5.5	0.8
6	0.8
6.5	0.8
7	0.6
7.5	0.4
8	0.2
8.5	0.05
9	0.01

- $K_m$  = 0 (assumes no loss due to metabolism of contaminants)  
 $\alpha_{ij}$  = see "paramtrs.xls" file on diskette  
 $K_i$  = see "paramtrs.xls" file on diskette for values for inorganics  
 $C_0$  = 0.011 @ 10°C (equilibrium solubility value)  
 $\delta$  = 0.002 @ 10°C (Thomann 1989)  
 $\beta$  = -0.25 (range -0.2 - -0.3) (Thomann 1989)  
 = 0.032 (range 0.014 - 0.05) (Thomann 1989)  
 = -0.2 (range -0.2 - -0.3) (Thomann 1989)

Predation fractions for aquatic organisms were determined using studies in the Hanford Reach and the general literature. Bivalve, snail, aquatic insect, toad larvae, and juvenile lamprey diets were estimated based on their feeding behavior (in other words, grazers, filter feeders; C.E. Cushing, Pacific Northwest National Laboratory, personal communication August 12, 1996) and the known ratios of periphyton, phytoplankton, particulate matter, and periphyton in the water column. Crayfish diet composition was taken from Pennak (1989). Feeding habits of resident and anadromous fish have been described in both reports and the open literature, including largescale sucker (Dauble 1986), smallmouth bass (Battelle 1979a, 1979b, 1978, 1977a, 1977b), carp (Battelle 1977b), Pacific lamprey (Scott and Crossman 1973), mountain whitefish (Battelle 1979a, 1979b, 1978, 1977a, 1977b), white sturgeon (Battelle 1979a, 1979b, 1978, 1977a, 1977b), channel catfish (Battelle 1979a, 1979b, 1978, 1977a, 1977b), rainbow trout (Battelle 1979a, 1979b, 1978, 1977a, 1977b), and juvenile chinook salmon (Becker 1973, Dauble et al.



1980). Relative proportions of food items were based on volume (Windell 1970), and items were grouped by taxonomic group to provide consistency with uptake parameters selected for the ingestion model. Predation fractions used in this model are shown in the “paramtrs.xls” file on diskette.

## Radiological Dose Estimation

The above exposure analyses return estimates of ingestion exposure to radiological contaminants in units of picocuries/kilogram body mass/day (units of radioactive decay rate density). However, radiological effects result from radioactive energy density absorbed by a body in a unit of time, which is usually expressed in units of rads/day. Consequently, decay rates had to be converted to energy equivalents. Similarly, an organism can receive external energy from radioactive decay occurring in the abiotic media (air, water, or soil). The primary media of concern to the ecological risk analysis are soil (in other words, sediment) and water.

The methodology that was used to estimate radiological doses in the ecological screening assessment followed that used in PNNL’s CRITTER2 code (Baker and Soldat 1992). CRITTER2 has two model components. One component estimates body burden from ingestion by means of transfer factors. The second component converts body burden to radiological dose and estimates external dose from radioactive decay in sediment and water. This second component of CRITTER2 was used in the CRCIA model.

## Dose Equations

Internal total-body dose rate to an organism is the sum of the individual dose rates from each radionuclide in the body:

$$R_{i,int} = \sum C_{i,c} * E_{i,c}$$

where

$R_{i,int}$  = radiological dose to organism  $i$  from internal radioactive decay (rad/day)

$C_{i,c}$  = specific body burden of nuclide  $c$  in organism  $i$  (pCi/kg)

$E_{i,c}$  = effective absorbed energy rate for nuclide  $c$  per unit activity in organism  $i$  (kg rad/pCi/day)

and doses are summed across all radionuclides.

As shown in Baker and Soldat (1992),  $E_{i,c}$  is a function of the effective absorbed energy in MeV/disintegration ( $E_{i,c}$ ), viz.

$$E_{i,c} = 1 \text{ Ci}/10^{12} \text{ pCi} * E_{i,c} \text{ MeV/disintegration} * 3.7E10 \text{ disintegrations/sec/Ci} \\ * 86,400 \text{ sec/day} * 1.602E-11 \text{ kg rad/MeV}$$

or

$$E_{i,c} = 5.12E-8 * E_{i,c}$$



External dose rates from water exposures are a similar sum of exposures from all radionuclide sources:

$$R_{i,imm} = \Sigma (b_{pore} * EC_{pore,c} + b_{surface} * EC_{surface,c}) * DF_{imm,c} * F_{water \rightarrow i} * CF_{water}$$

where

$R_{i,imm}$  = external radiological dose to organism i from exposure to radioactive decay in water (rad/day)

$DF_{imm,c}$  = water immersion dose factor for nuclide c (mrad m<sup>3</sup>/μCi/year)

$F_{water \rightarrow i}$  = fractional exposure of organism i to the water (unitless)

$CF_{water}$  = 3.65E-8 (conversion factor: μCi rad year/pCi/mrad/day)

and other variables are as defined previously.

Finally, external dose received from contact with sediments is calculated as:

$$R_{i,sed} = \Sigma EC_{sed,c} * DF_{sed,c} * F_{sed,i} * CF_{sed}$$

where

$R_{i,sed}$  = External radiological dose to organism i from exposure to radioactive decay in sediment (rad/day)

$DF_{sed,c}$  = Sediment dose factor for nuclide c (mrad m<sup>2</sup>/μCi/year)

$F_{sed,i}$  = Fractional exposure of organism i to the sediment (unitless)

$CF_{sed}$  = 5.4795E-5 (conversion factor: μCi rad year kg/pCi/m<sup>2</sup>/mrad/day) and other variables are as defined previously.

Finally, total radiological dose is obtained by summing the above quantities:

$$R_{i,total} = \Sigma (R_{i,imm} + R_{i,sed} + R_{i,int})$$

## Calibration

The environmental and body burden inputs to the above equations use field-derived media concentrations as described in Section 4.0 and body-burden estimates obtained from the air- and water-respiring species exposure equations described earlier. Dose factors and the effective absorbed energy in MeV/disintegration were obtained from Baker and Soldat (1992). Dose factors are a function of the radionuclide. Effective absorbed energies are a function of both the radionuclide and the radius of the organism being evaluated. Equivalent radii for each species were obtained by assuming organisms represent a sphere of unit density and by calculating radii from average body weight data, which were presented earlier.

## Calibration Parameters for Copper and Zinc

The exposure model was calibrated to produce approximate average tissue concentrations for copper and zinc within Segment 1. The calibration procedure focused on selecting ranges for bioconcentration



factors, ingestion assimilation fractions, and depuration rates from within the published ranges for these parameters that would produce estimates between one-half and five times the average tissue concentrations for species obtained from uncontaminated areas.

The calibration parameters used are in a Microsoft Excel file (“par-calb.xls”) on diskette. The file shows the chemical assimilation efficiency and, for both copper and zinc, the bioconcentration factors and total loss rates.

## **Environmental Hazard Quotients**

EHQs (the ratio of estimated exposure dose or concentration to LOEL endpoint values) were computed using the deterministic method for river segments and contaminants for each Tier II species. The EHQs that were 1 or greater identified segments, contaminants, and species that were evaluated further in the stochastic modeling.

The EHQs computed are in a compressed file (“ehq-det.exe”) on diskette. The compressed file will automatically decompress when opened (see instructions at the beginning of this appendix). In the file, the EHQ is given for each species by contaminant and location.

## **Risk Categories from Stochastic Modeling**

Species-contaminant-river segment combinations were classified into four groups based on results of the stochastic simulations: nominal, low, medium, and high potential risk. The categories were based on the proportion of the simulation results that exceeded  $LC_{50}/LD_{50}$  or LOEL endpoints. Results of these simulations are presented in a compressed file (“risk-cat.exe”) on diskette. The compressed file will automatically decompress when opened (see instructions at the beginning of this appendix). The file contains tables and graphs that show the resulting  $LC_{50}/LD_{50}$  or LOEL values for both aquatic and terrestrial species.