BACKGROUND DOCUMENT FOR THE HUMAN EXPOSURE MODULE FOR HWIR99 MULTIMEDIA, MULTIPATHWAY, AND MULTIRECEPTOR RISK ASSESSMENT (3MRA) MODEL

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DISCLAIMER

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Table of Contents

Section **Page**

1.0 Module Overview and Summary of Functionality 1-1
  1.1 Overview 1-1
  1.2 Summary of Functionality 1-2
2.0 Assumptions and Limitations 2-1

3.0 Methodology 3-1
  3.1 Inhalation Exposure Calculations 3-1
  3.2 Ingestion Exposure Calculations 3-6
  3.3 Infant Breast Milk Exposure 3-9

4.0 Implementation 4-1

5.0 References 5-1

Appendix A: Inputs and Outputs A-1

Figure

Number **Page**

4-1 Conceptual flow diagram of major functionality of Human Exposure Module 4-1

1.0 Module Overview and Summary of Functionality

1.1 Overview

The Human Exposure module calculates the applied dose (mg of constituent per kg of body weight), i.e. the "exposure," to human receptors from media and food concentrations calculated by other modules in the Multimedia, Multipathway and Multiple Receptor Risk Assessment (3MRA) Methodology. These calculations are performed for each receptor, cohort, exposure pathway, and year at each exposure area.[1] The Human Exposure module calculates exposures for two basic receptor types: residential receptors (residents and home gardeners) and farmers. Residential receptors may also be recreational fishers in addition to being a resident or home gardener. Farmers may be beef farmers or dairy farmers, and either type of farmer may also be a recreational fisher. The subcategories within residential receptors and farmers differ in the particular exposures they incur. For example, a resident (only) differs from a home gardener in that home gardeners are exposed to contaminated fruits and vegetables, but residents are not. Within each of the two basic receptor types, the Human Exposure module calculates exposures for 5 age cohorts: infants (ages 0-1 year), children ages 1-5 years, children ages 6-11 years, children ages 12-19 years, and adults (ages 20 years and up).

The media inputs that are needed for the Human Exposure Module include ambient air concentration (both vapor and particulate), soil concentration, ground water concentration, exposed vegetable concentration, protected vegetable concentration, exposed fruit concentration, protected fruit concentration, root vegetable concentration, beef concentration, milk concentration, and fish filet concentration for trophic level 3 and trophic level 4 fish. For vegetables and fruits, the terms "exposed" and "protected" refer to whether the edible portion of the plant is exposed to the atmosphere.

Exposure to humans other than infants may occur through eight pathways: inhalation of ambient air, inhalation of shower air, ingestion of ground water, ingestion of soil, ingestion of fruits and vegetables, ingestion of beef, ingestion of milk, and ingestion of fish. However, not all receptors are exposed via all of these pathways. Residents are exposed via inhalation of ambient air, inhalation of shower air, ingestion of ground water, and ingestion of soil. Home gardeners have the same exposures as a resident, plus exposure via ingestion of fruits and vegetables. All farmers are exposed via inhalation of ambient air, inhalation of shower air, ingestion of ground water, ingestion of soil, and ingestion of fruits and vegetables. In addition, beef farmers are

[1] See Table 1 in the Human Risk Module technical background document (U.S. EPA, 1999) for the list of receptors and cohorts and applicable exposure pathways.

exposed via ingestion of beef, and dairy farmers are exposed via ingestion of milk. Recreational fishers have the same exposures as one of the other receptor types plus fish ingestion. Not all age cohorts are exposed via all pathways; shower exposures are calculated only for adults and children ages 12 to 19 years.

Infant exposure occurs via breast milk ingestion. The Human Exposure Module tracks noninfant exposure by the eight pathways described above. For infant exposure via breast milk, the maternal exposure via all pathways must be summed. Therefore, infant exposures are calculated for eight maternal exposure configurations: resident, home gardener, beef farmer, dairy farmer, resident/recreational fisher, home gardener/recreational fisher, beef farmer/recreational fisher, and dairy farmer/recreational fisher. The mother is assumed to be an adult (as opposed to a teenager) for the purpose of calculating maternal dose in the infant breast milk pathway.

1.2 Summary of Functionality

The major computational functions performed by the Human Exposure Module are the following:

- *Time series management*. The Human Exposure Module determines the overall duration of the time period to be simulated, which could possibly be discontinuous, and the individual years within this duration to be simulated.

- *Calculation of time series exposure concentrations and doses from time series media and food concentrations*. This is the fundamental purpose of the Human Exposure Module and is performed by a set of equations specific to each exposure pathway and carcinogenic/noncarcinogenic chemical property.

These functionality issues are described in detail in Section 3.0.

2.0 Assumptions and Limitations

The exposure characterization methodology used in the Human Exposure Module reflects a number of assumptions and/or limitations, which are listed below.

- Study area is bounded at 2 km. EPA assumed that all significant exposure by human receptors occurs within 2 km of the source. Exposures are not evaluated for individuals residing outside of the 2-km study area, measured from the source periphery.

- *Human receptors are stationary*. EPA assumed in characterizing exposure that human receptors both reside and work at the receptor location identified for them during site characterization (i.e., the farm area for farmers or residential exposure area for nonfarmers). The point of exposure is, in general, the census block centroid for a resident and home gardener and the centroid of a farm for farmers. This assumption may overestimate or underestimate exposure, because it is possible that individuals may reside at the identified location within the study area but commute to work areas outside of the study area or could commute to more or less contaminated areas within the study area.

- *Incremental exposure is modeled*. The HWIR model generates incremental exposures in accordance with standard practice. No provision is made for considering background exposures for the purpose of generating cummulative or total risk, HQ, or MOE estimates for modeled receptors.

- *Homogeneous concentrations in fruits and vegetables are assumed*. The exposure methodology makes no provision for possible chemical concentration gradients within fruits or vegetables that might result in different concentrations in edible portions than when averaged throughout the food item.

- *Food preparation has no effect*. No diminution of chemical concentration in food items is assumed to occur through food preparation, e.g., washing of fruits and vegetables.

- Annual average concentrations/doses for exposure. No shorter term average or spikes evaluated. All outputs from this module are on an annual basis.

- Ingestion rates are age cohort specific. The ingestion and inhalation rates, as well as body weight, are based on the age cohort. For example, a 1 to 5-year-old child would ingest less water on a daily basis then a 6- to 10-year-old child.

3.0 Methodology

The methodology and equations used in the Human Exposure Module, with the exception of the breast milk algorithms and the shower/bathroom air concentration algorithms, were obtained from the April 1997 internal review draft of the *Methodology for Assessing Health Risks Associated with Multiple Exposure Pathways to Combustor Emissions* (U.S. EPA, in press), henceforth referred to as the IEM. The breast milk algorithms are from the December 1997 external review draft of the IEM (U.S. EPA, in press). These algorithms, particularly with respect to the calculation of contaminant concentration in the aqueous phase of breast milk, are subject to change. The shower algorithms are adapted from McKone (1987).

The Human Exposure Module performs calculations for residential receptors (residents and home gardeners) for a single x-y coordinate in each census block in each area of interest, and for farmers for a single farm in each census block group in the study area. The x-y coordinate for farmer locations is located at the centroid of the census block group or farm. Where census blocks or farms overlap the concentric, radial distance "rings," they are disaggregated into subblock groups or subfarms, each located exclusively in its respective ring. Populations are allocated to subblock groups or subfarms based on area-weighting, i.e., populations are assumed to be uniformly distributed spatially within a census block. Recreational fish exposures are calculated and averaged across up to three randomly selected reaches over the entire study area. The random selection of reaches is made once for recreational fishers who are residential receptors and once for recreational fishers who are farmers.

The equations used to convert chemical concentrations in environmental media or food into exposures are presented below. It should be understood that exposures are calculated as a time series, with one value for each year in the time period under consideration. The equations below are used for each year of the time series.

To calculate human exposure, receptor- and cohort-specific human exposure factors are used. These human exposure factors were selected and developed to characterize consumption rates, exposure durations, body weights, and the contaminated fractions for each receptor/cohort used in the analysis. In all cases they represent estimates of nationwide variability, being based on national data provided in the *Exposure Factors Handbook* (U.S. EPA, 1997). The data and derived distributions for the exposure factors used in the HWIR analysis are described in *Data Collection for the Hazardous Waste Identification Rule, Section 8: Human Exposure Factors* (U.S. EPA, 1999).

3.1 Inhalation Exposure Calculations

Inhalation exposures are expressed differently depending on whether the exposure is being evaluated for a carcinogenic effect or a noncarcinogenic effect. When inhalation exposures for carcinogenic effects are evaluated, the exposure is expressed as an applied dose in terms of mg/kg-day. However, when evaluating inhalation exposures for noncarcinogenic effects, the exposure is expressed as an ambient concentration in mg/m^3. Below are presented the calculations for inhalation exposures to carcinogens. The exposure module does no calculation for inhalation exposure to noncarcinogens; however, the module does output the ambient air concentration and air concentration from showering for use in the human risk module.

Ambient Air Inhalation Exposure for Carcinogens

$$Inh_{air} = \frac{C_{ambient} \times IR}{BW} \qquad (3\text{-}1a)$$

where

Inh_{air}	=	average daily intake for ambient air (mg/kg/d)
$C_{ambient}$	=	total ambient air concentration (mg/m^3) and is calculated as
IR	=	inhalation rate (m^3/d)
BW	=	body weight (kg)

$$C_{ambient} = (C_{vap} + PM_{10}) \times 0.001 \qquad (3\text{-}1b)$$

where

C_{vap}	=	vapor-phase air concentration (µg/m^3)
PM_{10}	=	particulate-phase air concentration of particles $\leq$10µ (µg/m^3)
0.001	=	units conversion factor (mg/µg).

Showering Inhalation Exposure for Carcinogens

$$Inh_{shower} = \frac{C_{sb} \times 1000 \times IR \times t_{sb} \times BF}{BW \times 24 \times 60} \qquad (3\text{-}2a)$$

where

Inh_{shower}	=	average daily intake for showering inhalation (mg/kg/d)
1,000	=	units conversion factor (L/m^3)
IR	=	inhalation rate (m^3/d)
t_{sb}	=	time in shower and bathroom (min/event)
BF	=	event frequency (events/d)
24	=	units conversion factor (h/d)
60	=	units conversion factor (min/h)
C_{sb}	=	average air concentration in bathroom and shower (mg/L), and is calculated as

$$C_{sb} = C_{shower} \times \left(\frac{t_{shower}}{t_{sb}} \right) + C_{bath} \times \left(\frac{t_{sb} - t_{shower}}{t_{sb}} \right) \tag{3-2b}$$

where

t_{shower}	=	shower time (min)
C_{shower}	=	average air concentration in the shower (mg/m^3)
C_{bath}	=	average air concentration in the bathroom (mg/m^3)

C_{shower} and C_{bath} are calculated as

$$C_{shower} = \sum_{t=0}^{t_{shower}/60} y_s(t) \tag{3-2c}$$

$$C_{bath} = \sum_{t=t_{shower}/60}^{t_{sb}/60} y_b(t) \tag{3-2d}$$

where

$y_s(t)$	=	gas-phase constituent concentration in the shower at time t (mg/L)
$y_b(t)$	=	gas-phase constituent concentration in the bathroom at time t (mg/L).

$y_s(t)$ and $y_b(t)$ are determined by solving a system of two, coupled, differential equations that describe the time-varying changes in average concentration in, respectively, the shower and the bathroom over the duration of a shower when the shower water is contaminated with chemical. (It should be noted that the dynamic response is not related to changes in the **inputs** to the system, e.g., chemical concentration in the tap water [which is constant intrayear], but rather changes in the shower and bathroom air concentrations resulting from injecting contaminated spray into an initially clean air environment.) Using a finite difference approximation to the time derivatives, the time series solutions (over the time duration of the shower, 20 minutes) for $y_s(t)$ and $y_b(t)$ are determined from a joint solution to Equations 3-2e and 3-2f below.

$$y_b(t+dt) = y_b(t) + \frac{\left(VR_{sb} \times \left[y_s(t) - y_b(t)\right] - VR_{bh} \times y_b(t)\right) \times dt}{V_{bath} \times 60 \times 1000} \qquad (3\text{-}2e)$$

$$y_s(t+dt) = y_s(t) + \frac{VR_{sb} \times \left[y_b(t) - y_s(t)\right] \times \left(\frac{dt}{60}\right) + E_s(t)}{V_{shower} \times 1000} \qquad (3\text{-}2f)$$

where

$y_b(t+dt)$ = gas-phase constituent concentration in the bathroom at end of time step starting at time t (mg/L)

$y_s(t+dt)$ = gas-phase constituent concentration in the shower at the end of time step starting at time t (mg/L)

dt = calculation time step (= 20 s)

VR_{sb} = volumetric gas exchange rate between shower and bathroom (L/min)

VR_{bh} = volumetric gas exchange rate between bathroom and house (L/min)

VR_{sb} = volumetric gas exchange rate between shower and bathroom (L/min)

V_{bath} = volume of bathroom (m^3)

V_{shower} = shower volume (m^3)

$E_s(t)$ = mass of constituent emitted from shower during the time step starting at time t (mg), and is calculated as

$$E_s(t) = \min(E_1(t), E_{max}(t)) \qquad If\ t \le tshower * 60 \qquad (3\text{-}2g)$$

$$E_s(t) = 0 \qquad If\ t > tshower * 60 \qquad (3\text{-}2h)$$

where

$E_1(t)$ = potential mass of constituent emitted from shower during time step beginning at time t (mg)

$E_{max}(t)$ = maximum mass of constituent available to be emitted from the shower during the time step starting at time t (mg)

$E_1(t)$ and $E_{max}(t)$ are calculated as

$$E_1(t) = C_{gw} \times R_{shower} \times \left(\frac{dt}{60}\right) \times (1 - f_{sat}(t))\left[1 - \exp\left(-\frac{6 \times K_{ol} \times Hh}{DD \times Vn}\right)\right] \qquad (3\text{-}2i)$$

$$E_{max}(t) = [41 \times H \times C_{gw} - y_s(t)] \times V_{shower} \times 1000 \qquad (3\text{-}2j)$$

where

C_{gw} = concentration in showering water (mg/L)
R_{shower} = shower volume (L/m)
Hh = nozzle height (cm)
DD = droplet diameter (cm)
Vn = terminal velocity of droplet (cm/s)
41 = factor that converts H into its dimensionless form
H = Henry's law constant (atm-m^3/mol)
1,000 = conversion factor (L/m^3)
K_{ol} = overall mass transfer coefficient (cm/s), and is calculated as

$$K_{ol} = 216 \times \left(\frac{2.5}{D_w^{2/3}} + \frac{1}{D_a^{2/3} \times 41 \times H}\right)^{-1} \qquad (3\text{-}2k)$$

where

216 = proportionality constant β $(cm/s)^{-1/3}$
D_w = diffusivity in water (cm^2/s)
D_a = diffusivity in air (cm^2/s)
$f_{sat}(t)$ = fraction of gas-phase saturation at time t (unitless), and is calculated as

$$f_{sat}(t) = \frac{y_s(t)}{41 \times H \times C_{gw}} \tag{3-2l}$$

3.2 Ingestion Exposure Calculations

There is no difference in the way ingestion exposures are estimated for carcinogens and non-carcinogens. All exposures are expressed as an applied dose in mg/kg-d. These are then used to calculate either risk or hazard quotients in the human risk module.

Soil Ingestion Exposure

$$Ing_{soil} = \frac{C_{soil} \times CR_{soil} \times F_{soil}}{BW} \tag{3-3}$$

where

Ing_{soil}	=	soil ingestion exposure (mg/kg/d)
C_{soil}	=	soil concentration (mg/kg)
CR_{soil}	=	soil ingestion rate (kg/d)
F_{soil}	=	fraction of consumed soil contaminated (dimensionless)
BW	=	body weight (kg)

Water Ingestion Exposure

$$Ing_{water} = \frac{C_{gw} \times CR_{water} \times F_{water}}{BW} \tag{3-4}$$

where

Ing_{water}	=	water ingestion exposure (mg/kg/day)
C_{gw}	=	groundwater concentration (mg/L)
CR_{water}	=	water ingestion rate (L/day)
F_{water}	=	fraction of consumed water contaminated (dimensionless)
BW	=	body weight (kg)

Total Vegetable and Fruit Ingestion Exposure

$$Ing_{veg} = Ing_{exveg} + Ing_{exfruit} + Ing_{proveg} + Ing_{profruit} + Ing_{root} \quad (3\text{-}5a)$$

where

Ing_{veg}	=	total vegetable and fruit ingestion exposure (mg/kg/d)
Ing_{exveg}	=	exposed vegetable ingestion exposure (mg/kg/d)
$Ing_{exfruit}$	=	exposed fruit ingestion exposure (mg/kg/d)
Ing_{proveg}	=	protected vegetable ingestion exposure (mg/kg/d)
$Ing_{profruit}$	=	protected fruit ingestion exposure (mg/kg/d)
Ing_{root}	=	root vegetable ingestion exposure (mg/kg/d)

These five contributing exposures to the total exposure are calculated from the following equations.

$$Ing_{exveg} = P_{exveg} \times CR_{exveg} \times 0.001 \times F_{exveg} \quad (3\text{-}5b)$$

$$Ing_{exfruit} = P_{exfruit} \times CR_{exfruit} \times 0.001 \times F_{exfruit} \quad (3\text{-}5c)$$

$$Ing_{proveg} = P_{proveg} \times CR_{proveg} \times 0.001 \times F_{proveg} \quad (3\text{-}5d)$$

$$Ing_{profruit} = P_{profruit} \times CR_{profruit} \times 0.001 \times F_{profruit} \quad (3\text{-}5e)$$

$$Ing_{root} = P_{root} \times CR_{root} \times 0.001 \times F_{root} \quad (3\text{-}5f)$$

where

P_{exveg}	=	concentration in exposed vegetables (mg/kg WW)
$P_{exfruit}$	=	concentration in exposed fruit (mg/kg WW)
P_{proveg}	=	concentration in protected vegetables (mg/kg WW)
$P_{profruit}$	=	concentration in protected fruit (mg/kg WW)
P_{root}	=	concentration in root vegetables (mg/kg WW)
CR_{exveg}	=	ingestion rate of exposed vegetables (g WW/kg/d)
$CR_{exfruit}$	=	ingestion rate of exposed fruit (g WW/kg/d)
CR_{proveg}	=	ingestion rate of protected vegetables (g WW/kg/d)

$CR_{profruit}$ = ingestion rate of protected fruit (g WW/kg/d)
CR_{root} = ingestion rate of root vegetables (g WW/kg/d)
F_{exveg} = fraction of exposed vegetables contaminated (dimensionless)
$F_{exfruit}$ = fraction of exposed fruit contaminated (dimensionless)
F_{proveg} = fraction of protected vegetables contaminated (dimensionless)
$F_{profruit}$ = fraction of protected fruit contaminated (dimensionless)
F_{root} = fraction of root vegetables contaminated (dimensionless)
0.001 = units conversion factor (kg/g)

Beef Ingestion Exposure

$$Ing_{beef} = A_{beef} \times CR_{beef} \times 0.001 \times F_{beef} \tag{3-6}$$

where

Ing_{beef} = beef ingestion exposure (mg/kg/d)
A_{beef} = beef concentration (mg/kg WW)
CR_{beef} = beef ingestion rate (g WW/kg/d)
0.001 = units conversion factor (kg/g)
F_{beef} = fraction of beef contaminated (dimensionless)

Milk Ingestion Exposure

$$Ing_{milk} = \frac{A_{milk} \times CR_{milk} \times 0.001 \times F_{milk}}{BW} \tag{3-7}$$

where

Ing_{milk} = milk ingestion exposure (mg/kg/d)
A_{milk} = milk concentration (mg/kg WW)
CR_{milk} = milk ingestion rate (g WW/kg/d)
0.001 = units conversion factor (kg/g)
F_{milk} = fraction of milk contaminated (dimensionless)
BW = body weight (kg)

Fish Ingestion Exposure

$$Ing_{fish} = \frac{C_{fish} \times CR_{fish} \times 0.001 \times F_{fish}}{BW} \tag{3-8a}$$

where

Ing_{fish} = fish ingestion exposure (mg/kg/d)
CR_{fish} = fish ingestion rate (g/d)
0.001 = units conversion factor (kg/g)
F_{fish} = fraction of fish contaminated (dimensionless)
BW = body weight (kg)
C_{fish} = consumption weighted fish concentration (mg/kg), and is calculated as

$$C_{fish} = C_{T3filet} \times F_{T3} + C_{T4filet} \times F_{T4} \tag{3-8b}$$

where

$C_{T3filet}$ = trophic level 3 fish filet concentration (mg/kg)
F_{T3} = fraction of fish consumed that is trophic level 3 (unitless)
$C_{T4filet}$ = trophic level 4 fish filet concentration (mg/kg)
F_{T4} = fraction of fish consumed that is trophic level 4 (unitless)

3.3 Infant Breast Milk Exposure

Infant breast milk exposure is calculated as

$$Ing_{BM} = \frac{[C_{milkfat} \times f_{mbm} + C_{aquous} \times (1 - f_{mbm})] \times f_{ai} \times CR_{bm} \times 0.001}{BW} \tag{3-9}$$

where

Ing_{BM} = ingestion of breast milk exposure (mg/kg/d)
f_{mbm} = fraction of fat in maternal breast milk (dimensionless)
f_{ai} = fraction of ingested contaminant absorbed by the infant (dimensionless)
CR_{bm} = ingestion rate of breast milk (mL/d)
0.001 = units conversion factor (kg/mL)
BW = body weight of infant (kg)
$C_{milkfat}$ = concentration in maternal milk fat (mg/kg)

$$C_{milkfat} = \frac{ADD_{mat} \times f_{am} \times f_f}{(ln2)/t^{b}_{1/2} \times f_{fm}} \tag{3-10}$$

where

f_{am} = fraction of ingested contaminant absorbed by the mother (dimensionless)

f_f	=	proportion of contaminant that is stored in maternal fat (dimensionless)
f_{fm}	=	fraction of mother's weight that is fat (dimensionless)
$t_{1/2}^{b}$	=	biological half-life of contaminant in lactating women (days)
ADD_{mat}	=	average daily dose consumed by the mother (mg/kg-d), and is calculated as

$$ADD_{mat} = (Inh_{air} + Inh_{shower} + Ing_{soil} + Ing_{water} + Ing_{veg} + Ing_{beef} + Ing_{milk} + Ing_{fish}) \times \frac{EF}{365} \quad (3\text{-}11)$$

where

Inh_{air}	=	average daily intake for ambient air (mg/kg/d)
Inh_{shower}	=	average daily intake for showering inhalation (mg/kg/d)
Ing_{soil}	=	soil ingestion exposure (mg/kg/d)
Ing_{water}	=	water ingestion exposure (mg/kg/d)
Ing_{veg}	=	total vegetable and fruit ingestion exposure (mg/kg/d)
Ing_{beef}	=	beef ingestion exposure (mg/kg/d)
Ing_{milk}	=	milk ingestion exposure (mg/kg/d)
Ing_{fish}	=	fish ingestion exposure (mg/kg/d)
EF	=	mother's exposure frequency (d/yr)
365	=	units conversion factor (d/yr)

$$C_{aqueous} = \frac{ADD_{mat} \times f_{am} \times f_{pl} \times k_{pm}}{(ln2)/t_{1/2}^{b} \times f_{pm}} \quad (3\text{-}12)$$

where

$C_{aqueous}$	=	concentration in aqueous phase of maternal milk (mg/kg), and is calculated as
f_{pl}	=	fraction of contaminant (based on total absorbed intake) that is in the blood plasma compartment (dimensionless)
k_{pm}	=	concentration proportionality constant between plasma and breast milk aqueous phase (dimensionless)
f_{pm}	=	fraction of mother's weight that is plasma (dimensionless)

4.0 Implementation

The flowchart shown in Figure 4-1 illustrates the generalized looping structure of the Human Exposure Module.

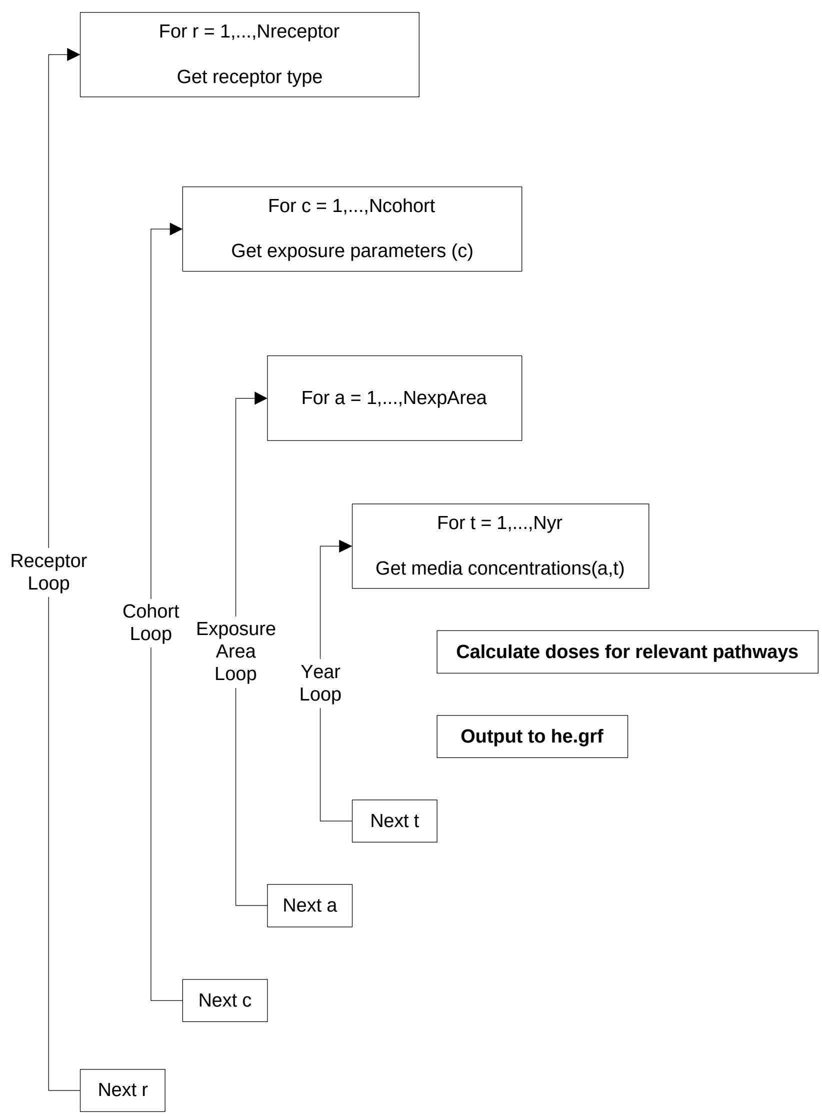

Figure 4-1. Conceptual flow diagram of major functionality of Human Exposure Module.

5.0 References

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Appendix A

Inputs and Outputs

Appendix A

Inputs and Outputs

The Human Exposure Module receives inputs from its module-specific input file, he.ssf, the generic site layout file (sl.ssf), the generic chemical properties file (cp.ssf), and modeled outputs from the following other modules: Aquifer Module (aq.grf) , Aquatic Food Web Module (af.grf), Farm Foodchain Module (ff.grf), Wateshed Module (ws.grf), Suface Water Module (sw.grf), Air Module (ar.grf), and those source modules outputting (to a common grf file, sr.grf) a "true" for the soil-presence logical flag, *SrcSoil*. (SrcSoil = true signifies that contaminated soil is present, which is an exposure pathway.) These sources are the Land Application Unit, Landfill, Wastepile, and Surface Impoundment. Human Exposure Module outputs are written to the he.grf file. (All exposure outputs except infant breastmilk exposures are three-dimensional arrays indexed on time, space, and age cohort. The spatial component may be x-y coordinate representing receptor locations as the centroid of a census block or farm represented by a set of x,y coordinates. Infant breast milk exposures are two-dimensional arrays on time and space. They apply to only one age cohort, infants, so there is no third dimension.)

All input and output variables are listed and described in Tables A-1 through A-8. Variable parameters are available in data report sections.

Table A-1. He.ssf Input Parameters (Module-specific Inputs)

Input Parameter	Units	Description
Bri_<cr#>	m^3/d	Cohort-specific inhalation rate for the four child resident cohorts (Note: “<cr#>” is replaced with the actual cohort designation in the variables used by the human exposure module)
Bri_r	m^3/d	Inhalation rate for the adult resident.
BW<cr#>	kg	Cohort-specific body weight for each of the four child cohorts (Note: this parameter is not differentiated for farmer versus non-farmer receptor)
BW_r	kg	Body weight for adult receptors
CRb_cf_<#>	gWW/kg/d	Beef consumption rate for the three farmer child cohorts 2-4 (Note: “<#>” is replaced with the actual cohort number in the variables used by the human exposure module)
CRb_af	gWW/kg/d	Beef consumption rate for the adult farmer
CRbm_cf_1	mL/d	Breast milk ingestion rate for the farmer infant
CRfr_cf_<#>	gWW/kg/d	Exposed fruit consumption rate for the three farmer child cohorts 2-4 (Note: “<#>” is replaced with the actual cohort number in the variables used by the human exposure module)
CRfr_f	gWW/kg/d	Exposed fruit consumption rate for the adult farmer
CRfr_cg_<#>	gWW/kg/d	Exposed fruit consumption rate for the three gardener child cohorts 2-4 (Note: “<#>” is replaced with the actual cohort number in the variables used by the human exposure module)
CRfr_g	gWW/kg/d	Exposed fruit consumption rate for the adult gardener
CRfs_c_<#>	gWW/kg/d	Home-caught fish consumption rate for the three child cohorts 2-4 (Note: “<#>” is replaced with the actual cohort number in the variables used by the human exposure module)
CRfs_a	gWW/kg/d	Home-caught fish consumption rate for the adult
CRl_cf_-#-	gWW/kg/d	Exposed vegetables consumption rate for the three farmer child cohorts 2-4 (Note: “<#>” is replaced with the actual cohort number in the variables used by the human exposure module)
CRl_f	gWW/kg/d	Exposed vegetables consumption rate for the adult farmer
CRl_cg_<#>	gWW/kg/d	Exposed vegetables consumption rate for the three gardener child cohorts 2-4 (Note: “<#>” is replaced with the actual cohort number in the variables used by the human exposure module)
CRl_g	gWW/kg/d	Exposed vegetables consumption rate for the adult gardener

(continued)

Table A-1 (continued)

Input Parameter	Units	Description
CRpfr_cf_<#>	gWW/kg/d	Protected fruit consumption rate for the three farmer child cohorts 2-4 (Note: “<#>” is replaced with the actual cohort number in the variables used by the human exposure module)
CRpfr_f	gWW/kg/d	Protected fruit consumption rate for the adult farmer
CRpfr_cg_<#>	gWW/kg/d	Protected fruit consumption rate for the three gardener child cohorts 2-4 (Note: “<#>” is replaced with the actual cohort number in the variables used by the human exposure module)
CRpfr_g	gWW/kg/d	Protected fruit consumption rate for the adult gardener
CRpl_cf_<#>	gWW/kg/d	Protected vegetables consumption rate for the three farmer child cohorts 2-4 (Note: “<#>” is replaced with the actual cohort number in the variables used by the human exposure module)
CRpl_f	gWW/kg/d	Protected vegetables consumption rate for the adult farmer
CRpl_cg_<#>	gWW/kg/d	Protected vegetables consumption rate for the three gardener child cohorts 2-4 (Note: “<#>” is replaced with the actual cohort number in the variables used by the human exposure module)
CRpl_g	gWW/kg/d	Root vegetables consumption rate for the adult gardener
CRr_cf_<#>	gWW/kg/d	Root vegetables consumption rate for the three farmer child cohorts 2-4 (Note: “<#>” is replaced with the actual cohort number in the variables used by the human exposure module)
CRr_f	gWW/kg/d	Root vegetables consumption rate for the adult farmer
CRr_cg_<#>	gWW/kg/d	Root vegetables consumption rate for the three gardener child cohorts 2-4 (Note: “<#>” is replaced with the actual cohort number in the variables used by the human exposure module)
CRr_g	gWW/kg/d	Root vegetables consumption rate for the adult gardener
CRw_cr_<#>	gWW/kg/d	Drinking water consumption rate for the four child cohorts 1-4 (Note: “<#>” is replaced with the actual cohort number in the variables used by the human exposure module)
CRw_r	gWW/kg/d	Drinking water consumption rate for the adult receptor
CRs_cr_<#>	gWW/kg/d	Incidental soil ingestion rate for the three child cohorts 2-4 (Note: “<#>” is replaced with the actual cohort number in the variables used by the human exposure module)
CRs_r	gWW/kg/d	Incidental soil ingestion rate for the adult receptor

(continued)

Table A-1 (continued)

Input Parameter	Units	Description
CRm_cf_<#>	gWW/kg/d	Milk consumption rate for the three child farmer cohorts 2-4 (Note: "<#>" is replaced with the actual cohort number in the variables used by the human exposure module)
CRm_af	gWW/kg/d	Milk consumption rate for the adult farmer receptor
DD	cm	Water droplet diameter
EFr	d/yr	Exposure frequency (adult resident)
F<dietary item>_<receptor category>	Unitless	Fraction of <dietary item> consumed (e.g., exposed fruit, exposed vegetables, beef, drinking water) that is contaminated (for the "f" farmer or "g" gardener). (Note: in the actual variable names, <dietary item> and <receptor category> are replaced with acronyms referring to appropriate terms - e.g., "m" for milk and "f" for farmer, respectively)
fbp	Unitless	Fraction of whole blood that is plasma
ffm	Unitless	Fraction of mother's weight that is fat
fmbm	Unitless	Fraction of fat in maternal breastmilk
fpm	Unitless	Fraction of mother's weight that is plasma
Fs	Unitless	Fraction of contaminated soil
FT<#>fish	Unitless	Fraction of fish consumed that is T# (i.e., T3 or T4)
Hn	cm	Shower nozzle height
Rshower	L/min	Shower rate
t_sb	min	Time in shower and bathroom
t_shower	min	Shower time
Vbath	m^3	Bathroom volume
Vn	cm/s	Terminal velocity of shower droplet
VRbh	L/min	Bathroom to house ventilation rate
Vrsb	L/min	Shower to bathroom ventilation rate
Vshower	m^3	Shower volume

Table A-2. Sl.ssf Input Parameters (Module-Specific Site Layout Inputs)

Input Parameter	Units	Description
FarmAquIndex	NA	Index of aquifer that impacts farm or crop area
FarmLWSIndex	NA	Local watershed indices associated with each farm
FarmLWSSubAreaFrac	Fraction	Fraction of contribution of subarea to farm
FarmLWSSubAreaIndex	NA	Index of contributing subarea in local watershed indices associated with each farm
FarmNumLWSSubArea	NA	Contributing subarea in local watershed indices associated with each farm
FarmNumWSSub	Unitless	Number of watersheds that impact farm or crop area
FarmWBNIndex	NA	Index of WBN that impacts farm or crop area
FarmWBNRchIndex	NA	Index of WBN reach that impacts farm or crop area
FarmWSSubFrac	Unitless	Fraction of each watershed on farm
FarmWSSubIndex	NA	Index of watersheds that impact farm or crop area
focS	Mass fraction	Fraction organic carbon (soil)
HumRcpAirIndex	NA	Index of air points that impact receptor
HumRcpAquIndex	Unitless	Index of aquifer that impacts receptor
HumRcpAquWellIndex	Unitless	Index of well that impacts receptor for the given aquifer
HumRcpLWSIndex	NA	Local watershed index for each human receptor
HumRcpLWSSubAreaInde	NA	Local watershed subarea index for each human receptor
HumRcpPh	pH units	Average shower water pH
HumRcpTemp	° Celsius	Typical shower temperature
HumRcpWSSubIndex	NA	Index of watershed that impacts receptor
NumFarm	Unitless	Number of farm or crop areas
NumHumRcp	Unitless	Number of human receptor points at a site
NumWBN	Unitless	Number of waterbody networks
NyrMax	Years	Maximum model simulation time
TermFrac	Fraction	Peak output fraction for simulation termination

(continued)

Table A-2. (continued)

Input Parameter	Units	Description
WBNFishableRchIndex	Unitless	Index of reaches that are fishable
WBNNumFishableRch	Unitless	Number of fishable reaches

Table A-3. Cp.ssf (Module-Specific Chemical Inputs)

Input Parameter	Units	Description
ChemBreast MilkExp	Unitless	Causes breast milk exposure? (1=yes, 0=no)
ChemCSFfood	$(mg/kg\text{-}d)^{-1}$	Cancer slope factor (food ingestion)
ChemCSFinhal	$(mg/kg\text{-}d)^{-1}$	Cancer slope factor (inhalation)
ChemCSFwater	$(mg/kg\text{-}d)^{-1}$	Cancer slope factor (drinking water ingestion)
ChemRfC	mg/m^3	Reference concentration (inhalation)
ChemRfDfish	mg/kg-d	Reference dose (fish ingestion)
ChemRfDfood	mg/kg-d	Reference dose (food ingestion)
ChemRfDwater	mg/kg-d	Reference dose (drinking water ingestion)
Chemfai	Fraction	Fraction of ingested contaminant by the infant which is absorbed
ChemFam	Fraction	Fraction of contaminant ingested by mother that is absorbed
ChemFbl	Fraction	Fraction of contaminant in whole blood compartment
ChemFf	Fraction	Fraction of contaminant stored in maternal fat
Chemkpm	Unitless	Concentration proportionality constant between plasma and breast milk aqueous phase
ChemKrbc	Unitless	Concentration proportionality constant between red blood cells and plasma
Chemt_halfb	d	Biological half-life of chemical in lactating women
ChemADiff	cm^2/s	Air diffusion coefficient
ChemHLC	$(atm\ m^3)/mol$	Henry's law constant
ChemWDiff	cm^2/s	Water diffusion coefficient

Table A-4. *Af.ssf* Input Variables (Aquatic Food Web Module Inputs)

Input Parameter	Units	Description
CT3filet	mg/kg WW	Chemical concentration in trophic level 3 fish filet
CT4filet	mg/kg WW	Chemical concentration in trophic level 4 fish filet

Table A-5. Ff.ssf (Farm Food Chain Module Inputs)

Input Parameter	Units	Description
CTssAve_farm	µg/g	Chemical concentration in surficial soil averaged over farm area
CtssAve_farmYR	Unitless	Time series of years corresponding to this variable
CTssAve_farmNY	Unitless	Number of years in the time series corresponding to this variable
Abeef_farm	mg/kg WW	Modeled beef concentration
Abeef_farmYR	Unitless	Time series of years corresponding to this variable
Abeef_farmNY	Unitless	Number of years in the time series corresponding to this variable
Amilk_farm	mg/kg WW	Modeled milk concentration
Amilk_farmYR	Unitless	Time series of years corresponding to this variable
Amilk_farmNY	Unitless	Number of years in the time series corresponding to this variable
P<vegetable or fruit type>_farm	mg/kg WW	Modeled concentration for specific fruit and vegetable categories (e.g., <vegetable or fruit type> would be replaced by: “exveg”, “proveg” or “root” for exposed vegetables, protected vegetables or root vegetables, respectively) raised on farms
P<vegetable or fruit type>_farmYR	Unitless	Time series of years corresponding to this variable
P<vegetable or fruit type>_farmNY	Unitless	Number of years in the time series corresponding to this variable
P<vegetable or fruit type>_garden	mg/kg WW	Modeled concentration for specific fruit and vegetable categories (e.g., <vegetable or fruit type> would be replaced by: “exveg”, “proveg” or “root” for exposed vegetables, protected vegetables or root vegetables, respectively) raised in home gardens
P<vegetable or fruit type>_gardenYR	Unitless	Time series of years corresponding to this variable
P<vegetable or fruit type>_gardenNY	Unitless	Number of years in the time series corresponding to this variable

Table A-6. Sr.ssf Input Variables (Generic Source Module Inputs)

Input Parameter	Units	Description
SrcSoil	NA	Flag for soil presence
CTss	µg/g	Soil concentration (annual average, all subareas)
CTssYR	Unitless	Time series of years corresponding to this variable
CTssNY	Unitless	Number of years in the time series corresponding to this variable

NA = Not applicable

Table A-7. Ar.ssf Input Variables (Air Module Inputs)

Input Parameter	Units	Description
PM10	µg/m^3	Concentration of particles = 10 microns
PM10YR	Unitless	Time series of years corresponding to this variable
PM10NY	Unitless	Number of years in the time series corresponding to this variable
CVap	µg/m^3	Concentration of chemical in air vapor
CVapYR	Unitless	Time series of years corresponding to this variable
CVapNY	Unitless	Number of years in the time series corresponding to this variable

Table A-8. Ws.ssf Input Variables (Watershed Module Inputs)

Input Parameter	Units	Description
CTssR	µg/g	Surface soil concentrations for modeled watersheds
CTssYR	Unitless	Time series of years corresponding to this variable
CTssNY	Unitless	Number of years in the time series corresponding to this variable

Table A-9. He.grf Output Variables (Human Exposure Module Outputs)

Input Parameter	Units	Description
IngBM<pathway>H	mg/kg-d	Chemical- and pathway-specific average daily dose for the nonfarmer infant resulting from breast milk ingestion. (Note: "<pathway>" denotes the actual pathway name in the variables generated by the human exposure module.)
IngBM<pathway>HYR	Unitless	Time series of years corresponding to this variable.
IngBM<pathway>HNY	Unitless	Number of years in the time series corresponding to this variable
IngBM<pathway>F	mg/kg-d	Chemical- and pathway-specific average daily dose for the farmer infant resulting from breast milk ingestion (Note: "<pathway>" denotes the actual pathway name in the variables generated by the human exposure module.)
IngBM<pathway>FYR	Unitless	Time series of years corresponding to this variable
IngBM<pathway>FNY	Unitless	Number of years in the time series corresponding to this variable
Cambient_Farm	mg/m^3	Farm area-specific modeled ambient air concentration used in evaluating inhalation risk; separate estimates are generated for each modeled year
Cambient_FarmYR	Unitless	Time series of years corresponding to this variable
Cambient_FarmNY	Unitless	Number of years in the time series corresponding to this variable
Cambient_HumRcp	mg/m^3	Residential location-specific modeled ambient air concentration used in evaluating inhalation risk; separate estimates are generated for each modeled year
Cambient_HumRcpYR	Unitless	Time series of years corresponding to this variable
Cambient_HumRcpNY	Unitless	Number of years in the time series corresponding to this variable
Csb_Farm	mg/m^3	Farm area-specific modeled shower/bath air concentration used in evaluating inhalation risk; separate estimates are generated for each modeled year
Csb_FarmYR	Unitless	Time series of years corresponding to this variable
Csb_FarmNY	Unitless	Number of years in the time series corresponding to this variable

(continued)

Table A-9. (continued)

Input Parameter	Units	Description
Csb_HumRcp	mg/m^3	Residential location-specific modeled shower/bath air concentration used in evaluating inhalation risk; separate estimates are generated for each modeled year
Csb_HumRcpYR	Unitless	Time series of years corresponding to this variable
Csb_HumRcpNY	Unitless	Number of years in the time series corresponding to this variable
Ing<pathway>_Farm	mg/kg-d	Chemical- and pathway- specific average daily dose for the farmer resulting from ingestion of the dietary item identified as the "pathway" by the variable (Note: "<pathway>" denotes the actual pathway name in the variables generated by the human exposure module.)
Ing<pathway>_FarmYR	Unitless	Time series of years corresponding to this variable
Ing<pathway>_FarmNY	Unitless	Number of years in the time series corresponding to this variable
Ing<pathway>_HumRcp	mg/kg-d	Chemical- and pathway- specific average daily dose for the non-farmer resulting from ingestion of the dietary item identified as the "pathway" by the variable (Note: "<pathway>" denotes the actual pathway name in the variables generated by the human exposure module.)
Ing<pathway>_HumRcpYR	Unitless	Time series of years corresponding to this variable
Ing<pathway>_HumRcpNY	Unitless	Number of years in the time series corresponding to this variable