5.0 EXPOSURE FACTORS FOR NONGROUNDWATER PATHWAYS

All exposure factors used in the risk assessment for the petroleum waste listing decision have been reviewed and are consistent with the EPA guidance presented in the 1990 *Exposure Factors Handbook*. These values used are documented in the risk equations in which they are used in Appendix A of this document. The values for all exposure factors used in the risk assessment for the proposed rule and the reanalysis are identical except for ingestion of root vegetables. The wrong value for ingestion of root vegetables was used in the analysis for the proposed rule; the correct value was used in the reanalysis. The values presented in column 3 of Table 5.1 were used in the reanalysis.

A 1996 update of the 1990 *Exposure Factors Handbook* has been published in draft form and is currently available to the public (U.S. EPA, 1996a). Copies can be obtained from NTIS. The document numbers are:

- Volume I - PB97-117683
- Volume II - PB97-117691
- Volume III - PB97-117709
- Set of Volumes I-III - PB97-117675.

The document can also be viewed at all EPA libraries and through the Internet. The Internet address is www.epa.gov/ord/whatsnew.htm. This draft document will be revised and issued as final in the Summer 1997. Exposure factors critical to the petroleum risk assessment (e.g., soil ingestion) are unlikely to change between draft and final versions of the handbook. The Agency may use exposure factors from the 1997 final version for the final rule. Based on a preliminary analysis of key exposure factors, the Agency does not believe that use of updated exposure factors will significantly change the outcome of the risk assessment presented in this NODA. The preliminary analysis is provided in Appendix D of this document.

The soil ingestion rate for the home gardener remained constant in the revised analysis as indicated in Table 5.1; however, the source of ingested soil has been revised to represent soil from the untilled residential plot instead of representing soil from the tilled home garden as assumed in the proposed rule.

The values for the meteorologic parameters used in this analysis are identical to those used in the risk analysis for the proposed rule. These values are used consistently throughout both analyses although typographical errors appeared in some tables in the background document for the proposed rule. The values used for the meteorologic-dependent parameters used in the analysis conducted for the proposed rule and in this revised analysis are presented in Table 5.2.

Table 5.1 Exposure Factors Used in Risk Assessment

Exposure Factor	Central Tendency Adult Exposure (Proposed Rule)	Central Tendency Adult (Reanalysis)
Soil ingestion	100 mg/d[a]	100 mg/d
Aboveground produce (DW) ingestion	19.7 g/d	19.7g/d
Root vegetable (WW) ingestion	1.4 g/d	**28 g/d**[b]
Fish, ingestion (fisher scenarios)	Subsistence - 60 g/d	Subsistence - 60 g/d
	Recreational - 30 g/d	Recreational - 30 g/d
Beef, ingestion	57 g/d	57 g/d
Milk, ingestion	181 g/d	181 g/d

Source: U.S.EPA, 1990.

[a] Standard type face indicates no change from the proposal.

[b] Revised exposure factors are boldfaced.

Table 5.2 Meteorologic Parameters Used in Risk Analysis

Parameter	Central Tendency (Houston, TX)	High End (Los Angeles, CA)
Annual Precipitation (cm/yr)	119.1	28.7
Annual Evapotranspiration (cm/yr)	22.73	7.31
Annual Runoff Value (cm/yr)	13	1.3
Annual Infiltration Rate (cm/yr)	83.7	20.09

6.0 SHOWER MODEL AND EXPOSURE FACTORS FOR INHALATION AND DERMAL RISK FROM RESIDENTIAL USE OF GROUNDWATER

The multimedia multipathway exposure model used for the proposed petroleum waste listing determination did not include inhalation or dermal exposures to constituents in residential tap water. In response to public comments, shower inhalation exposure models were evaluated for inclusion of these pathways in the groundwater risk analysis for the petroleum waste listing. A detailed discussion of the model review and selection process is provided in Appendix C.

6.1 Description of Shower Model

The shower model used in this analysis is based the equations presented in McKone (1987). The shower model estimates the change in the shower air concentration based on the mass of constituent lost by the water (fraction emitted or emission rate) and the air exchange rate between the various model compartments (shower, the rest of the bathroom, and the rest of the house) following the same basic model construct described by Little (1992). The resulting differential equations were solved using finite difference numerical integration. These equations are presented in detail in Appendix A, Equations A-5.1 through A-5.9.

The basis for estimating the concentration of constituents in the indoor air is based on the mass transfer of constituent from water to shower air.

This equation estimates the overall mass transfer coefficient from tap water to air from showering:

$$K_{ol} = \beta \times \left(\frac{2.5}{D_1^{2/3}} + \frac{1}{D_a^{2/3} H'} \right)^{-1} \qquad (6\text{-}1)$$

where

K_{ol} = overall mass transfer coefficient (cm/s)
β = proportionality constant $(cm/s)^{-1/3}$
D_1 = diffusion coefficient in water (cm^2/s)
D_2 = diffusion coefficient in air (cm^2/s)
H' = Dimensionless Henry's law constant ($=41*H_{LC}$).

The constituent emission rate is estimated from the change in the shower water concentration as the water falls, which is calculated using the overall mass transfer coefficient as follows:

$$\delta c/\delta t = -K_{ol}(A/V)(c - y_s/H') \qquad (6\text{-}2)$$

where

c = liquid phase (droplet) constituent concentration (μg/cm^3 or mg/L)
t = time (s)
A = total surface area for mass transfer (cm^2)
V = total volume of water within the shower compartment (cm^3)
y_s = gas phase constituent concentration in the shower (μg/cm^3 or mg/L)
H' = dimensionless Henry's law constant.

Consequently, in addition to the overall mass transfer coefficient, the emission rate of a contaminant within the shower is dependent on the surface-area-to-volume ratio of the shower water (within the shower) and the concentration driving force between the water and the shower air.

The shower emissions can be modeled based on falling droplets as a means of estimating the surface-area-to-volume ratio for mass transfer and the residence time of the water in the shower compartment. Equation 6-2 can then be integrated assuming the compound concentration in the gas phase is constant over the time frame of the droplet fall. The time required for a droplet to fall equals the nozzle height divided by the water droplet velocity. The ratio of the surface area to volume for the droplet is calculated as $6/d_p$ (i.e., by assuming a spherical shape). By assuming the drops fall at terminal velocity, the surface-area-to-volume ratio and the residence time can be determined based solely on droplet size. A droplet size of approximately 1 mm (0.1 cm) was selected. The terminal velocity for the selected droplet size is approximately 400 cm/s. The fraction of constituent emitted from a water droplet at any given time can then be calculated by integrating Equation 6-2 and rearranging as follows:

$$f_{em} = 1 - C_{out}/c_{in} = (1 - f_{sat})(1 - e^{-N}) \tag{6-3}$$

where

f_{em} = fraction of constituent emitted from the droplet (dimensionless)
c_{out} = droplet constituent concentration at shower floor/drain (mg/L)
c_{in} = droplet constituent concentration entering the shower (mg/L)
f_{sat} = $y_s/(H' c_{in})$ = fraction of gas phase saturation (dimensionless)
N = dimensionless overall mass transfer coefficient = $K_{ol}\,(6/d_p)\,(h/v_t)$
d_p = droplet diameter = 0.1 (cm)
v_t = terminal velocity of droplet = 400 (cm/s)
h = nozzle height (cm).

The gas phase constituent concentration in the shower is then calculated for each time step for the duration of the shower. The air exchange rate between the shower and the bathroom is included in the estimation of the gas phase concentration of the constituents in the shower.

$$y_{s,t+1} = y_{s,t} + [Q_{gs} \times (y_{b,t} - y_{s,t}) \times (t_{t+1} - t_t) + E_{s,t}]/V_s \tag{6-4}$$

where

$y_{s,t+1}$ = gas phase constituent concentration in the shower at the end of time step (mg/L)
$y_{s,t}$ = gas phase constituent concentration in the shower at the beginning of time step (mg/L)
Q_{gs} = volumetric gas exchange rate between shower and bathroom (L/min)

$y_{b,t}$ = gas phase constituent concentration in the bathroom at the beginning of time step (mg/L)
$(t_{t=1}\text{-}t_t)$ = calculation time step
$E_{s,t}$ = mass of constituent emitted from shower between time t and time t+1 (mg)
V_s = volume of shower stall (L)

The shower model also provides direct estimates of the bathroom and whole house exposure. The risk from inhalation exposures in the remainder of the house was several orders of magnitude less than the risk from inhalation exposures in the bathroom and during showering (Coburn, 1996). The gas phase constituent concentration in the bathroom may be estimated by Equation 6-5 for each time step of the exposure duration.

$$y_{b,t+1} = y_{b,t} + \{[Q_{gs} \times (y_{s,t} - y_{b,t})] - [Q_{gb} \times (y_{b,t} - y_{h,t})] + (I_b \times C_{in} \times f_{em,b})\} \times \left(\frac{t_{t+1} - t_t}{V_b}\right) \qquad (6\text{-}5)$$

where

$y_{b,t+1}$ = gas phase constituent concentration in the bathroom at end of time step (mg/L)
$y_{b,t}$ = gas phase constituent concentration in the bathroom at beginning of time step
Q_{gs} = volumetric gas exchange rate between bathroom and house
$yt_{h,t}$ = gas phase constituent concentration in the house at beginning of time step (mg/L)
$(T_{t+1}\ \text{-}t_t)$ = calculation time step (min)
I_b = bathroom water use (L/min)
C_{in} = constituent concentration in tap water (mg/L)
$f_{em,b}$ = fraction of constituent emitted from bathroom water use (unitless)
V_b = volume of bathroom (L).

The gas phase constiuent concentration in the remainder of the house may be estimated by Equation 6-6 for each time step of the exposure duration.

$$y_{h,t+1} = y_{h,t} + \{[Q_{gb} \times (y_{b,t} - y_{h,t})] - [Q_{gh} \times (y_{h,t} - y_{a,t})] + (I_h \times C_{in} \times f_{em,h})\} \times \left(\frac{t_{t+1} - t_t}{V_h}\right) \qquad (6\text{-}6)$$

where

$y_{h,t+1}$ = gas phase constituent concentration in the house at end of time step (mg/L)
$y_{h,t}$ = gas phase constituent concentration in the house at beginning of time step (mg/L)
Q_{gb} = volumetric gas exchange rate between the bathroom and house (L/min)
$y_{b,t}$ = gas phase constituent concentration in the bathroom at beginning of time step (mg/L)

Q_{gh} = volumetric gas exchange rate between the house and atmosphere (L/min)
$y_{a,t}$ = gas phase constituent concentration in the atmosphere (mg/L)
$(T_{t+1} - t_t)$ = calculation time step (min)
I_h = house water use - other than bathroom (L/min)
C_{in} = constituent concentration in tap water (mg/L)
$f_{em,h}$ = fraction of constituent emitted from household water use - other than bathroom (unitless)
V_h = volume of house (L).

The average air concentration in the shower and bathroom are obtained by averaging the concentrations obtained for each time step over the duration of the shower and bathroom use. These concentrations and the durations of daily exposure are used to estimate risk from inhalation exposures to residential use of groundwater.

6.2 Exposure Factors

Where available, the exposure parameters used in this analysis are central tendency values cited in the *Exposure Factors Handbook* (U.S. EPA, 1996a). The remaining exposure factors required for this analysis were obtained from McKone (1987). The original articles have been obtained to verify the values used in the analysis. All parameter values are presented in Table 6.1. The physical and chemical parameters for the constituent of concern (benzene) are presented in Table 6.2. These data were used to determine a relative risk factor that may be used to estimate the inhalation risk based upon the risk estimated for the ingestion of contaminated groundwater. The groundwater concentrations are provided in the *Supplemental Background Document; Groundwater Pathways Risk Analysis; Petroleum Refining Process Waste Listing Determination* (HydroGeoLogic, Inc., 1997). The results of this inhalation risk analysis are presented in that document as well.

Showering with contaminated tap water containing 1 mg/L of benzene results in an inhalation risk of 6.06 E-5. The risk value is directly proportional to the concentration of benzene in the water and thus a ratio may be applied to the benzene concentration in groundwater to determine the risk from shower inhalation. The risk values are provided in HydroGeoLogic, Inc., (1997).

The equations used in the estimation of risk from the inhalation exposure during showering pathway are presented in Appendix A. These equations are consistent with the approach presented in the Hazardous Waste Identification Rule (HWIR).

Table 6.1 Exposure Factors Used to Determine Risk from Inhalation Exposure to Contaminated Tap Water

Exposure Factor	Parameter Value	Reference
Shower duration	10.4 min	U.S. EPA, 1996a
Shower rate	5.5 L/min	McKone, 1987
Shower volume	2.30 m^3	U.S. EPA, 1996a
Water use	15 gal/d per person (median)	McKone, 1987
Bathroom volume	13.6 m^3	U.S. EPA, 1996a
House volume	310 m^3	U.S. EPA, 1996a
Shower vent rate	100 L/min	McKone, 1987
Bathroom vent rate	300 L/min	McKone, 1987
House vent. rate	0.45 air changes/h (2,325 L/min)	McKone, 1987
Bathroom water use	33 gal/d (125 L/d)	McKone, 1987
Fem, bathroom	0.50	McKone, 1987
Time toilet emits	1 h/d	McKone, 1987
House water use (tot)	53 gal/d (201 L/d)	McKone, 1987
Fem, house water	0.66	McKone, 1987
Time house water emits	16 h/d	McKone, 1987
Inhalation rate	13.8 L/min	U.S. EPA, 1990

Table 6.2 Physical and Chemical Properties of Benzene Used in Shower Inhalation Exposure Model

Property	Value	Reference
Henry's law constant	5.4 E -3 atm-m^3/mol	U.S. EPA, 1996a
Diffusivity in air	8.8 E -2 cm^2/s	U.S. EPA, 1996a
Diffusivity in water	9.8 E -6 cm^2/s	U.S. EPA, 1996a

6.3 Dermal Exposure to Tap Water

Another noningestion route of exposure to groundwater not considered in the groundwater risk assessment for the proposed rule is dermal exposure from bathing and showering. In response to public comments, this pathway has been added to the exposures from ingestion of drinking water and showering for waste streams in which benzene was present in groundwater. The basic equation (U.S. EPA 1992) used in this analysis for benzene (time of exposure ≥ time to steady-state) is

$$DA_{event} = C_{water} \times K_p^{w} \left[\frac{t_{event}}{1+B} + 2\tau \left(\frac{1+3B}{1+B} \right) \right] \times \frac{1}{10^3} \qquad (6\text{-}7)$$

where

DA_{event} = dose absorbed per unit area per event (mg/cm^2)
C_{water} = water concentration (mg/L)
K_p^{w} = skin permeability constant in water (cm/h)
t_{event} = duration of event (h)
τ = lag time (h)
B = bunge constant (unitless)
$1/10^3$ = L/ cm^3.

The risk due to dermal exposures is much less than the risk from inhalation or ingestion exposure to the same concentration of benzene. The equations used in the estimation of risk from the dermal exposure during showering or bathing pathway are presented in Appendix A.

7.0 CODISPOSAL SCENARIOS

Commenters noted that many of the waste streams addressed by the proposed listing decision contain many of the same constituents and are frequently disposed of in the same treatment or disposal units. In response to this comment, EPA conducted an analysis of risk associated with codisposal of multiple petroleum waste streams. EPA first identified land treatment units in which petroleum residuals were actually codisposed. The analysis included both the petroleum listing residuals as well as 15 other wastes for which EPA collected data (see SAIC 1997). Four of the units in which codisposal occured are onsite and three are offsite facilities. Site-specific LTU areas and waste quantities were used in the analysis. Only waste streams containing PAHs of concern were considered for the analysis in the nongroundwater risk assessment of codisposal scenarios. In addition, clarified slurry oil (CSO) sludge was not considered in codisposal scenarios because it presents sufficient risk when disposed of independently to be proposed for listing as a hazardous waste and, therefore, would no longer be disposed of in nonhazardous LTUs.

7.1 Codisposal in Onsite Land Treatment Units

Table 7.1 presents the four onsite land treatment units in which petroleum wastes are codisposed (SAIC, 1997). Two of these four LTUs (058-2 and 101-12) were not modeled because the codisposed streams did not contain significant levels of PAHs. One unit (170-5) was not modeled because crude oil tank sludge was the only waste stream that was not excluded from consideration based on PAH content or proposed listing status. Only one onsite land treatment unit (171-3) was identified as a site where petroleum wastes (other than CSO) that contain PAHs were actually codisposed.

The actual waste combinations and quantities disposed of in this unit were used as inputs to the risk assessment with one exception. EPA did not have the actual quantity of off-specification products and fines that was codisposed in this unit. Therefore, we conservatively used a quantity of 34 t, the maximum amount of off-specification product and fines that was managed in an onsite LTU. Each waste that was codisposed in unit 171-3 was assumed to be placed separately in the LTU and each stream was modeled individually using assumptions for variations in meteorologic data, distance to receptor, concentration of constituents, and duration of exposure and methodology used for single waste stream analysis. The resulting risks for each waste stream codisposed in the land treatment unit were summed to determine total risk for the LTU. For example, the high-end risks for the close receptor, long exposure duration off-specification products and fines was added to the high-end risks for the close receptor, long exposure duration for crude oil tank sludge placed in the same treatment unit. This was true for each pair of high-end variables. The results of the analysis of the onsite codisposal scenario are presented in Section 15.

7.2 Codisposal in Offsite Land Treatment Units

Three offsite land treatment units were identified as sites in which PAH-containing petroleum residuals were actually codisposed (SAIC, 1997). Table 7.2 presents the offsite codisposal scenarios identified for evaluation. Two of the three units were modeled. One unit (Facility No. 2) was not evaluated because it contained CSO sludge and another waste stream that did not contain significant concentrations of PAHs. As in the case of the onsite land treatment units, actual waste stream combinations and quantities disposed of in LTUs were identified. As in the case of the onsite codisposal scenarios, each waste stream in the combination was modeled independently. However, instead of evaluating specific sizes of offsite LTUs, the size distribution identified for all offsite treatment units was considered for offsite codisposal because it would be possible for refiners to send wastes to any nearby offsite facility. The 50th percentile offsite LTU area (29.9 acres) was used for both offsite LTU codisposal scenarios. Thus, the unique quantity of each waste identified as being codisposed at Facilities 1 and 3 was assumed to be placed separately in a 29.9 acres LTU and modeled individually using the standard assumptions for variations in meteorologic data, distance to receptor, concentration of constituents, and duration of exposure used for individual waste streams. The resulting risks for each combination of high-end variables for each waste stream codisposed in offsite land treatment units were added to obtain the total risk of the codisposal scenario as described for the onsite codisposal scenarios. The results of the analysis of the onsite codisposal scenario are also presented in Section 15.

Table 7.1 Nonhazardous Onsite Land Treatment Units and Codisposal Waste Streams

Waste Management Unit			
Unit	Area (acres)	Waste Stream	Waste Quantity (t)
058-2[a]	0.6	Desalting sludge	299
		HF alkylation sludge	3.7
		Unleaded gasoline tank sludge	2
101-12[a]	3	Sulfur complex sludge	258
		HF alkylation sludge	9
170-5[b]	15.8	FCC catalyst	512
		Unleaded gasoline tank sludge	11.77
		Crude oil tank sludge	NR
		CSO sludge	2,520
		Off-spec products and fines	1
171-3[c]	7.5	Sulfur complex sludge	50
		Crude oil tank sludge	65
		Off -spec products and fines	34[d]

CSO = Clarified slurry oil.
FCC = Fluidized catalytic cracking.
NR = Not reported.

[a] Waste streams codisposed in this unit did not contain significant quantities of PAHs.

[b] This LTU was not modeled because neither FCC catalyst nor unleaded tank sludge contain PAHs and CSO sludge was not considered because of proposal to list CSO as hazardous.

[c] LTU used for an onsite codisposal analysis.

[d] Volume disposed of in hazardous unit was used because volume for this unit was not reported.

Table 7.2 Nonhazardous Offsite Land Treatment Units and Codisposal Waste Streams

Waste Management Unit	Waste Stream	Waste Quantity (t)
Facility No. 1	Crude oil tank sludge	53.9
	Off-spec products and fines	21.2
Facility No. 2[a]	CSO sludge	2277.75
	Desalting sludge	22.2
Facility No. 3	Crude oil tank sludge	11.12
	CSO sludge	111.4[a]
	Desalting sludge	29

CSO = Clarified slurry oil.

[a] This unit was not evaluated