Korea
National Oil Corporation

Appendix J2

Model Description and Worked Example

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J2-1.0 INTRODUCTION

This appendix provides an example of the calculations used to estimate media concentrations and human exposures to the chemicals of potential concern (COPCs) from long-term (chronic) multiple pathway way exposures to the emissions resulting from the Korea National Oil Corporation (KNOC) Blackgold Expansion Project (the project). Many of the methods, equations and assumptions used to predict concentrations in various environmental media were provided by the United States Environmental Protection Agency Office of Solid Waste (US EPA OSW 2005) and Health Canada (2004). Potential multiple pathway exposures to the COPCs were predicted for the residents and workers using the highest annual average concentrations or the highest incremental increase in concentrations predicted at various locations within the health regional study area (RSA).

In order to quantify potential human exposures (and associated health impacts) through the oral pathway as a result of emissions from the project, predicted chemical concentrations in various environmental media were required to estimate exposures and characterize risks. Chemical concentrations in the following media were estimated based on predicted annual air concentrations:

- Soil
- Surface water (i.e., lakes)
- Vegetation
- Dusts
- Wild game meat (moose, grouse, snowshoe hare)
- Fish

In addition to providing the equations and algorithms used to estimate environmental media concentrations, the following sections provide the methods used to estimate human chemical exposures and predict risks. A worked example is provided for an adult resident exposed to benzo(a)pyrene as a result of the project alone.

J2-2.0 ENVIRONMENTAL MEDIA CONCENTRATIONS

J2-2.1 Chemical Concentrations in Air

The maximum predicted annual average ground-level air concentration of the 37 resident locations and the local maximum point of impingement (MPOI) was used to predict environmental concentrations for calculating game meat concentrations. Maximum annual air concentrations were used to estimate soil, forage, surface water and invertebrate concentrations to which wildlife are exposed. The maximum annual average concentration of benzo(a)pyrene for all locations, the exceptions being the worker housing complexes, as a result of the project alone was determined to be 0.00000082 µg/m³ or *8.2E-07 µg/m³*. All media concentrations used to predict animal exposures can be found in Appendix J2-A Predicted Game Meat Concentrations.

Similarly, the maximum predicted annual average ground-level air concentration of all 37 resident locations was used to predict concentrations of garden produce (above and below ground) and traditional plants (cattail, Labrador tea, and berries). This air concentration was also used to estimate soil, dust, surface water and fish concentrations to which humans could be exposed. The maximum annual average concentration of benzo(a)pyrene for the 37 resident locations as a result of the project alone was determined to be 0.00000052 µg/m³ or *5.2E-07 µg/m³*. All media concentrations used to predict human exposures can be found in Appendix J2-B Multiple Pathway Exposure Model.

J2-2.1.1 Chemical Deposition

J2-2.1.1.1 Dry Deposition

Dry deposition rates were estimated with the following equation:

$$D_{dry} = C_a \times V_d \times CF1 \times CF2$$

Where:

D_{dry} = deposition rate of COPC (mg/m²/year)

C_a = COPC concentration in air (Table J2-A-7 or Table J2-B-13, µg/m³)

V_d = dry deposition velocity for COPC (Table J2-A-22 or Table J2-B-25; 1.00E-02 m/s, extrapolated from Wesley and Hicks 2000)

CF1 = conversion factor from seconds per day (31,536,000 sec/year)

CF2 = conversion factor from µg to mg (0.001 mg)

Example J2-1 **Dry deposition rate of benzo(a)pyrene for prediction of animal exposure.**

$$D_{dry} = 8.2E-07 \times 0.0100 \times 31{,}536{,}000 \times 0.001$$

$$D_{dry} = 2.6E-04\ mg/m^2/yr$$

Example J2-2 **Dry deposition rate of benzo(a)pyrene for prediction of human exposure.**

$$D_{dry} = 5.2E-07 \times 0.0100 \times 31{,}536{,}000 \times 0.001$$

$$D_{dry} = 1.6E-04\ mg/m^2/yr$$

J2-2.1.1.2 Wet Deposition

Wet deposition rates were estimated with the following equation:

$$D_{wet} = C_a \times V_w \times CF1 \times CF2$$

Where:

D_{wet} = deposition rate of COPC (mg/m²/year)

C_a = COPC concentration in air (Table J2-A-7 or Table J2-B-13; µg/m³)

V_w = wet deposition velocity for COPC (Table J2-A-22 or Table J2-B-25; 2.89E-03 m/s, extrapolated from Mackay 1991)

CF1 = conversion factor from seconds per day (31,536,000 sec/year)

CF2 = conversion factor from µg to mg (0.001 mg)

Example J2-3 Wet deposition rate of benzo(a)pyrene for prediction of animal tissue concentrations

$$D_{wet} = 8.2E-07 \times 0.00289 \times 31{,}536{,}000 \times 0.001$$

$$D_{wet} = 7.5E-05\ mg/m^2/yr$$

Example J2-4 Wet deposition rate of benzo(a)pyrene for prediction of human exposure

$$D_{wet} = 5.2E-07 \times 0.00289 \times 31{,}536{,}000 \times 0.001$$

$$D_{wet} = 4.7E-05\ mg/m^2/yr$$

J2-2.1.1.3 Total Deposition

Total deposition rates were estimated with the following equation:

$$D_{tot} = D_{dry} + D_{wet}$$

Where:

D_{tot} = deposition rate of COPC (Table J2-A-7 or Table J2-B-13; mg/m²/year)

D_{dry} = dry deposition (mg/m²/year)

D_{wet} = wet deposition (mg/m²/year)

Example J2-5 **Total deposition rate of benzo(a)pyrene for prediction of animal tissue concentrations**

$$D_{tot} = 2.6E-04 + 7.5E-05$$

$$D_{tot} = 3.3E-04\ mg/m^2/yr$$

Example J2-6 **Total deposition rate of benzo(a)pyrene for prediction of human exposure**

$$D_{tot} = 1.6E-04 + 4.7E-05$$

$$D_{tot} = 2.1E-04\ mg/m^2/yr$$

J2-2.2 Chemical Concentrations in Water

Surface water concentrations were used to predict exposure to wildlife via ingestion, and human exposure via fish consumption, dermal exposure and ingestion (as a drinking water source and incidentally while swimming). For wildlife exposure, surface water concentrations were predicted at an unnamed lake closest to the project, and for human exposure, surface water concentrations were predicted at Christina Lake. The surface area and depth of each lake along with the calculated amount of deposition was used to predict the surface water concentration.

J2-2.2.1 Mass of Deposition to Lake Surface

The deposition at the unnamed lake was calculated using the maximum predicted annual average ground-level air concentration of *8.2E-07 µg/m³*, which corresponds with a deposition rate of *3.3E-04 mg/m²/yr.*

The deposition at Christina Lake was calculated using the maximum predicted annual average ground-level air concentration for the resident of *5.2E-07 µg/m³*, which corresponds with a deposition rate of *2.1E-04 mg/m²/yr.*

The total amount of benzo(a)pyrene deposited to the each lakes surface was estimated with the following equation:

$$TML_{sw} = D_{tot} \times LA$$

Where:

TML_{sw} = total mass load to the lake surface over period of deposition (mg/yr)

D_{tot} = deposition rate of COPC (3.3E-04 or 2.1E-04, mg/m²/year)

LA = lake area (Table J2-A-35 or Table J2-B-38; m²)

Example J2-7 **Mass of benzo(a)pyrene loaded to unnamed lake for the prediction of surface water concentrations.**

$$TML_{sw} = 3.3E-04 \times 500{,}000$$

$$TML_{sw} = 1.6E+02\ mg/yr$$

Example J2-8 **Mass of benzo(a)pyrene loaded to Christina Lake for the prediction of surface water concentrations.**

$$TML_{sw} = 2.1E-04 \times 21{,}300{,}000$$

$$TML_{sw} = 4.5E+03\ mg/yr$$

J2-2.2.2 Surface Water Concentrations

Surface water concentrations in the unnamed lake and Christina Lake were calculated with the following modified equation (US EPA OSW 2005):

$$C_{sw} = \frac{TML_{sw} \times CF}{L_f \times L_{wc} + K_{sw} \times V_l}$$

Where:

C_{sw} = concentration in surface water (Table J2-A-7 or J2-B-13; mg/L)

TML_{sw} = total mass load to the lake over period of deposition (1.6E+02 or 4.5E+03; mg/yr)

L_f = lake flow rate (Table J2-A-35 or J2-B-38; m³/year)

L_{wc} = fraction of total water body for mixing (Table J2-A-35 or J2-B-38; assumed 100%)

K_{sw} = COPC surface water loss constant (Table J2-A-24 or J2-B-30; 3.57 yr^{-1})

V_l = lake volume (Table J2-A-35 or J2-B-38; m³)

CF = conversion factor from m³ to Litres (0.001 m³/L)

Example J2-9 Concentration of benzo(a)pyrene in unnamed lake.

$$C_{sw} = \frac{1.6E+02 \times 0.001}{400{,}000 \times 1 + 3.57 \times 4{,}000{,}000}$$

$$C_{sw} = 9.1E-08\ mg/L$$

Example J2-10 Concentration of benzo(a)pyrene in Christina Lake.

$$C_{sw} = \frac{4.5E+03 \times 0.001}{79{,}000{,}000 \times 1 + 3.57 \times 369{,}000{,}000}$$

$$C_{sw} = 3.3E-09\ mg/L$$

J2-2.3 Chemical Concentrations in Soil

J2-2.3.1 Measured Chemical Concentrations in Soil

The multiple pathway exposure model predicted soil concentrations based on atmospheric deposition.

J2-2.3.2 Predicted Incremental Chemical Concentrations in Soil

Soil concentrations were estimated based on the calculated chemical-specific deposition rates. Deposition to soil on a mass basis was calculated using the following equation:

$$D_s = \frac{D_{tot}}{Z_s \times BD}$$

Where:

D_s = chemical-specific deposition (mg/kg/year)

D_{tot} = chemical-specific deposition rate (Table J2-A-7 or J2-B-13; mg/yr)

Z_s = soil mixing zone depth (Table J2-A-29 or Table J2-B-35; 0.02 m or 0.2 m)

BD = soil bulk density (Table J2-A-29 or Table J2-B-35 1,500 kg/m³)

For the current assessment, the bulk density was assumed to be 1,500 kg/m³, and soil concentrations were predicted for two mixing depths (i.e., 2 cm and 20 cm) to calculate surface soil and soil concentrations, respectively.

Example J2-11 **Deposition of benzo(a)pyrene to surface soil for prediction of animal tissue concentrations.**

$$D_s = \frac{3.3E-04}{0.02 \times 1{,}500}$$

$$D_s = 1.1E-05\ mg/kg/yr$$

Example J2-12 **Deposition of benzo(a)pyrene to surface soil for prediction of human exposure.**

$$D_s = \frac{2.1E-04}{0.02 \times 1{,}500}$$

$$D_s = 7.0E-06\ mg/kg/yr$$

Example J2-13 **Deposition of benzo(a)pyrene to soil for prediction of animal tissue concentrations.**

$$D_s = \frac{3.3E-04}{0.2 \times 1{,}500}$$

$$D_s = 1.1E-06\ mg/kg/yr$$

Example J2-14 **Deposition of benzo(a)pyrene to soil for prediction of human exposure.**

$$D_s = \frac{2.1E-04}{0.2 \times 1{,}500}$$

$$D_s = 7.0E-07\ mg/kg/yr$$

J2-2.3.3 Calculating Chemical Loss Constants

Chemicals may be lost from soil by leaching, runoff, erosion, biotic and abiotic degradation, and volatilization. Only abiotic and biotic degradation and volatilization processes were considered for this assessment. The total rate at which a chemical is lost from soil was designated as *kt*.

J2-2.3.3.1 Chemical Loss via Biotic and Abiotic Degradation

The soil half-life values for abiotic and biotic degradation (i.e., ks) were obtained from the Canadian Council of Ministries of the Environment (CCME 2000), Mackay et al. (1992), the US EPA OSW (2005) or literature. The US EPA OSW (2005) recommends a soil loss constant (ks) of 0.48 yrs^{-1} for benzo(a)pyrene (Table J2-A-23 or Table J2-B-29).

J2-2.3.3.2 Chemical Loss via Volatilization

Chemical loss from volatilization was predicted as follows (Swan et al. 1979):

$$t_{1/2} = 1.58E-08 \times \left(\frac{K_{oc} \times S}{VP} \right)$$

Where:

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

K_{oc} = organic carbon partition coefficient (Table J2-A-20 or Table J2-B-24; 969,000 L/kg)

S = water solubility (Table J2-A-19 or Table J2-B-21; 0.0016 mg/L)

VP = vapour pressure (Table J2-A-18 or Table J2-B-20; 5.5E-09 mmHg)

The half-life is then converted to a rate constant (yrs^{-1}) using the following equation:

$$kv = \frac{0.693}{\left(t_{1/2} / 365 \right)}$$

Example J2-15 Chemical loss or degradation from soil as a result of volatilization of benzo(a)pyrene.

Soil half-life:

$$t_{1/2} = 1.58E-08 \times \left(\frac{969{,}000 \times 0.0016}{5.5E-09} \right)$$

$$t_{1/2} = 4{,}454 \; days$$

Loss as a result of volatilization:

$$kv = \frac{0.693}{\left(4{,}454 / 365 \right)}$$

$$kv = 0.057 \; yrs^{-1}$$

J2-2.3.3.3 Total Soil Loss Constant

$$kt = ks + kv$$

Where:

kt = chemical-specific soil loss constant as a result of all processes (Table J2-A-23 or Table J2-B-29; yrs^{-1})

ks = chemical-specific soil loss constant as a result of abiotic and biotic degradation (Table J2-A-23 or Table J2-B-29; 0.48 yrs^{-1})

kv = chemical-specific soil loss constant as a result of volatilization (Table J2-A-23 or Table J2-B-29; 0.057 yrs^{-1})

Example J2-16 Total soil loss constant as a result of all processes for benzo(a)pyrene.

$$kt = 0.48 + 0.057$$

$$kt = 0.54\ yrs^{-1}$$

J2-2.3.4 Calculation of Soil Concentrations

Soil concentrations were calculated on a mass per mass basis (mg/kg) based on the following equation:

$$C_s = \frac{D_s \times [1 - \exp(-kt \times tD)]}{kt}$$

Where:

C_s = average soil concentration over exposure duration (Table J2-A-7 or Table J2-B-13; mg/kg soil)

D_s = deposition to surface soil or soil (mg of chemical/kg of soil/year)

kt = chemical soil loss constant due to all processes (degradation or loss due to volatilization) (Table J2-A-23 or Table J2-B-29; 0.54 yrs^{-1})

tD = time period over which deposition occurs (Table J2-A-28 or Table J2-B-34; 75 years)

Example J2-17 Concentration of benzo(a)pyrene in surface soil for prediction of animal tissue concentrations.

$$C_s = \frac{1.1E-05 \times [1 - \exp(-0.54 \times 75)]}{0.54}$$

$$C_s = 2.1E-05\ mg/kg$$

Example J2-18 Concentration of benzo(a)pyrene in surface soil for prediction of human exposure.

$$C_s = \frac{7.0E-06 \times [1 - \exp(-0.54 \times 75)]}{0.54}$$

$$C_s = 1.3E-05\ mg/kg/yr$$

Example J2-19 Concentration of benzo(a)pyrene in soil for prediction of animal tissue concentrations.

$$C_s = \frac{1.1E-06 \times [1 - \exp(-0.54 \times 75)]}{0.54}$$

$$C_s = 2.1E-06\ mg/kg$$

Example J2-20 Concentration of benzo(a)pyrene in soil for prediction of human exposure.

$$C_s = \frac{7.0E-07 \times [1 - \exp(-0.54 \times 75)]}{0.54}$$

$$C_s = 1.3E-06\ mg/kg/yr$$

J2-2.4 Chemical Concentrations in Dust

The chemical concentrations in dust were calculated using the measured and/or predicted soil concentration, as follows:

$$C_{dust} = DL \times C_s \times CF$$

Where:

C_{dust} = chemical concentration in dust (Table J2-A-7 or Table J2-B-13; µg/m³)

DL = dust level (kg/m³)

C_s = surface soil concentration from deposition over time (Table J2-A-7 or Table J2-B-13; mg/kg)

CF = conversion factor from mg to µg (1,000 µg/mg)

A dust level (DL) of 0.76 µg/m³ (7.6E-10 kg/m³) was measured by Health Canada (2004) based on the average airborne concentration of respirable particulate matter (<10 µm aerodynamic diameter).

Example J2-21 Concentration of benzo(a)pyrene in dust for prediction of animal tissue concentrations.

$$C_{dust} = 7.6E-10 \times 2.1E-05 \times 1{,}000$$

$$C_{dust} = 1.6E-11\ \mu g/m^3$$

Example J2-22 Concentration of benzo(a)pyrene in dust for prediction of human exposure.

$$C_{dust} = 7.6E-10 \times 1.3E-05 \times 1{,}000$$

$$C_{dust} = 9.9E-12\ \mu g / m^3$$

J2-2.5 Chemical Concentrations in Vegetation

The methodology used to estimate the contribution from each route of the chemical uptake in vegetation is described in the following sections. The following mechanisms were included when estimating the uptake of the chemicals into the tissue of plants.

- air to above-ground plants (particle deposition to leaves or foliage)
- air to above-ground plants (vapour transfer to leaves or foliage)
- soil to above-ground plants (root uptake)
- soil to below-ground plants (root uptake)

J2-2.5.1 Aboveground Leafy Plant Concentrations as a Result of Direct Deposition

J2-2.5.1.1 Concentrations in Aboveground Forage/Browse Consumed by Wildlife

Atmospheric deposition was only considered for plants whose edible portions are above ground and where the chemical potentially exists in particulate form.

The following equation was used to predict concentrations of browse and aboveground plants for consumption by wildlife as a result of deposition processes on a dry weight (DW) basis:

$$Pd = \frac{\left[D_d + (D_w \times 0.6)\right] \times Rp \times \left[1.0 - \exp(-kp \times Tp)\right]}{Yp \times kp}$$

Where:

Pd = browse concentration as a result of direct deposition (Table J2-A-7; mg/kg DW)

D_d = dry deposition, particle fraction = (D_{dry} x (1-Fv)) (2.6E-04 x (1 – 0.294) = 1.8E-04 mg/m²/yr)

D_w = wet deposition, particle fraction = (D_{wet} x (1-Fv)) (7.5E-05 x (1- 0.294) = 5.3E-05 mg/m²/yr)

Fv = fraction that is volatile (Table J2-A-21; 29.4%)

Rp = intercept fraction of edible portions of plant (0.5; unitless)

kp = plant surface loss coefficient (Table J2-A-27; 18 yr^{-1})

Tp = length of plant exposure to deposition per harvest of the edible portion of the ith plant group (Table J2-A-27; 0.12 yr)

Yp = yield or productivity (Table J2-A-27; 0.24 kg DW/m²)

The US EPA OSW (2005) recommends the use of the default intercept fraction of edible portions of plant (*Rp*) value (unitless), because it represents the most current information available with respect to productivity and relative ingestion rates. A default *Rp* value of 0.5 was recommended for forage/browse.

The *kp* value is a measure of the amount of contaminant lost as a result of removal by wind and water and growth dilution. The US EPA OSW (2005) recommends a default *kp* value of 18 yr^{-1} for both forage/browse and produce, which corresponds to a 14-day half-life.

The US EPA OSW (2005) recommends using a *Yp* value of 0.24 kg DW/m² for forage/browse vegetation.

Example J2-23 Concentration of benzo(a)pyrene in forage/browse as a result of direct deposition for prediction of animal tissue concentrations.

$$Pd = \frac{\left[1.8E-04+\left(5.3E-05\times 0.6\right)\right]\times 0.5\times\left[1.0-\exp\left(-18\times 0.12\right)\right]}{0.24\times 18}$$

$$Pd = 2.2E-05\ mg/kg\ DW$$

J2-2.5.1.2 Concentrations in Aboveground Garden Produce Consumed by Humans

The same equation was used to predict concentrations in above ground garden plants for human consumption as a result of direct deposition. The plant concentration was calculated on a wet weight (WW) basis with the following equation.

$$Pd = \left(\frac{\left[D_d+\left(D_w\times 0.6\right)\right]\times Rp\times\left[1.0-\exp\left(-kp\times Tp\right)\right]}{Yp\times kp}\right)\times WPF\times\left(1-WC\right)$$

Where:

Pd = plant concentration as a result of direct deposition (Table J2-A-9; mg/kg WW)

D_d = dry deposition, particle fraction = (D_{dry} x (1-Fv)) (1.6E-04 x (1 – 0.294) = 1.1E-04 mg/m²/yr)

D_w = wet deposition, particle fraction = (D_{wet} x (1-Fv)) (4.7E-05 x (1- 0.294) = 3.3E-05 mg/m²/yr)

Fv = fraction that is volatile (Table J2-B-22; 29.4%)

Rp = intercept fraction of edible portions of plant (0.39; unitless)

kp = plant surface loss coefficient (Table J2-B-33; 18 yr^{-1})

Tp = length of plant exposure to deposition per harvest of the edible portion of the ith plant group (Table J2-B-33; 0.16 yr)

Yp = yield or productivity (Table J2-B-33; 2.24 kg DW/m²)

WPF = washing and peeling factor (Table J2-B-37; 1.0; unitless)

WC = water or moisture content of plant (Table J2-B-33; 85%, US EPA OSW 2005)

The US EPA OSW (2005) recommends the use of the default intercept fraction of edible portions of plant (*Rp*) value, (unitless), because it represents the most current information available with respect to productivity and relative ingestion rates. A default *Rp* value 0.39 was recommended for garden produce (US EPA OSW 2005).

The *kp* value is a measure of the amount of contaminant lost as a result of removal by wind and water and growth dilution. The US EPA OSW (2005) recommends a default *kp* value of 18 yr^{-1} for both forage/browse and produce, which corresponds to a 14-day half-life.

The US EPA OSW (2005) recommends using a *Yp* value of 2.24 kg DW/m² for garden produce ingested by humans.

Typically, a washing and peeling factor of 0.85 is recommended (US EPA OSW 2005), but the current assessment did not use this factor in order to account for potential exposures where washing or peeling does not occur.

Example J2-24 Concentration of benzo(a)pyrene in aboveground garden produce as a result of direct deposition for prediction of human exposure.

$$Pd = \left(\frac{\left[1.1E-04 + \left(3.3E-05 \times 0.6\right)\right] \times 0.39 \times \left[1.0 - \exp\left(-18 \times 0.16\right)\right]}{2.24 \times 18} \right) \times 1.0 \times \left(1 - 0.85\right)$$

$$Pd = 1.8E-07 \; mg/kg \; WW$$

J2-2.5.2 Aboveground Plant Concentrations as a Result of Vapour Uptake

The concentration of chemicals in aboveground plants (forage, garden produce) from direct vapour uptake was calculated using a mass-based air-to-plant biotransfer factor, which was derived from the volumetric air-to-plant biotransfer factor.

J2-2.5.2.1 Volumetric air-to-plant biotransfer factor

$$\log B_{vol} = 1.065 \times \log K_{ow} - \log\left(\frac{H}{R \times T}\right) - 1.654$$

Where:

B_{vol} = volumetric air-to-plant biotransfer factor (unitless; WW basis)

log K_{ow} = log of the octanol-water partition coefficient (Table J2-A-16 or Table J2-B-19; 6.0; unitless)

H = Henry's Law constant of the compound (Table J2-A-17 or Table J2-B-19; 1.10E-06 atm m³/mol)

R = gas constant (Table J2-A-30 or Table J2-B-36; 0.000082 atm m³/ mol)

T = room temperature in Kelvin (Table J2-A-30 or Table J2-B-36; 288 K)

Example J2-25 Volumetric air-to-plant biotransfer factor of benzo(a)pyrene.

$$\log B_{vol} = 1.065 \times 6.0 - \log\left(\frac{1.10E-06}{0.000082 \times 288}\right) - 1.654$$

$$B_{vol} = 1.2E+09$$

J2-2.5.2.2 Mass-based air-to-plant biotransfer factor

$$B_v = \frac{\rho_{air} \times B_{vol}}{(1 - WC) \times \rho_{forage}}$$

Where:

B_v = mass-based air-to-plant biotransfer factor ([µg/g DW plant] / [µg/g air])

P_{air} = density of air (1.19 g/L; Weast 1981)

B_{vol} = volumetric air-to-plant biotransfer factor (1,168,997,695 unitless; WW basis)

WC = water or moisture content of plant (Table J2-A-26, 63% for forage; Table J2-B-33, 85% for garden produce)

P_{forage} = density of forage (770 g/L; McCrady and Maggard 1993)

Example J2-26 Mass-based air-to-plant biotransfer factor for benzo(a)pyrene in forage for prediction of animal tissue concentrations.

$$B_v = \frac{1.19 \times 1{,}168{,}997{,}695}{(1 - 0.63) \times 770}$$

$$B_v = 4.9E+06\ [\mu g / g\ DW\ plant] / [\mu g / g\ air]$$

Example J2-27 Mass-based air-to-plant biotransfer factor for benzo(a)pyrene in aboveground garden produce for prediction of human exposure.

$$B_v = \frac{1.19 \times 1{,}168{,}997{,}695}{(1-0.85)\times 770}$$

$$B_v = 1.2E+07\ [\mu g / g\ DW\ \ plant]/[\mu g / g\ air]$$

J2-2.5.2.3 Concentrations in Aboveground Forage/Browse Consumed by Wildlife

The following equation was used to calculate aboveground plant tissue concentrations as a result of vapour uptake:

$$Pv = \frac{C_{air} \times (B_v / RF) \times F_v}{\rho_{air}}$$

Where:

Pv = COPC concentration in plant (Table J2-A-7; mg/kg DW)

C_{air} = COPC concentration in air (Table J2-A-7; 8.2E-07 µg/m³)

B_v = mass-based air-to-plant biotransfer factor ([µg/g DW plant] / [µg/g air])

RF = reduction factor (100 for PAHs)

F_v = fraction of chemical in vapour phase (Table J2-A-21; 29.4%)

P_{air} = density of air (1,200 g/m³; Weast 1981)

As recommended by the US EPA OSW (2005), the biotransfer factor for organics (except dioxins and furans) should be reduced by a factor of 100.

Example J2-28 Concentration of benzo(a)pyrene in forage/browse as a result of vapour uptake for prediction of animal tissue concentrations.

$$Pv = \frac{8.2E-07 \times (4.9E+06/100)\times 0.294}{1{,}200}$$

$$Pv = 9.8E-06\ mg / kg\ DW$$

J2-2.5.2.4 Concentrations in Aboveground Garden Produce Consumed by Humans

The following equation was used to calculate aboveground plant tissue concentrations as a result of vapour uptake:

$$Pv = \frac{C_{air} \times (B_v / RF) \times F_v \times VG_{ag}}{\rho_{air}} \times WPF \times (1 - WC)$$

Where:

Pv	=	COPC concentration in plant as a result of vapour uptake (Table J2-B-13; mg/kg WW)
C_{air}	=	COPC concentration in air (Table J2-B-13; 5.2E-07 µg/m³)
B_v	=	mass-based air-to-plant biotransfer factor ([µg/g DW plant] / [µg/g air])
RF	=	reduction factor (100% for PAHs)
F_v	=	fraction of chemical in vapour phase (Table J2-B-22; 29.4%)
VG_{ag}	=	empirical correction factor (0.01 or 1.0; US EPA OSW 2005)
P_{air}	=	density of air (1,200 g/m³; Weast 1981)
WPF	=	washing and peeling factor (Table J2-B-37; 1.0; unitless)
WC	=	water or moisture content of produce (Table J2-B-33; 85%, US EPA OSW 2005)

In the calculation of chemical concentrations in garden produce for human consumption, a washing and peeling factor of 0.85 is typically applied (US EPA OSW 2005). However, in the current assessment no adjustment was made assuming that washing and peeling was not performed.

As recommended by the US EPA OSW (2005), the biotransfer factor for organics (except dioxins and furans) should be reduced by a factor of 100. In addition the US EPA OSW (2005) also recommends an empirical correction factor (i.e., VG_{ag}) of 0.01 for COPCs with a log K_{ow} greater than 4 and an empirical correction factor of 1 for COPCs with a log K_{ow} less than 4. This additional empirical correction factor was not applied to the exposure pathways for ingestion of forage/browse by wildlife, but was applied to the exposure pathway for ingestion of plants for the human exposure assessment. A conversion from dry weight to wet weight (1 - WC) was also made to calculated concentrations in garden produce.

Example J2-29 **Concentration of benzo(a)pyrene in aboveground garden produce as a result of vapour uptake for prediction of human exposure.**

$$Pv = \frac{5.2E-07 \times (1.2E+07/100) \times 0.294 \times 0.01}{1{,}200} \times 1.0 \times (1-0.85)$$

$$Pv = 2.3E-08\ mg/kg\ WW$$

J2-2.5.3 Aboveground Plant Concentrations as a Result of Root Uptake

Contaminants present in soil can be taken up into edible portions of aboveground plants. The US EPA OSW (2005) provides an equation to predict aboveground plant concentrations as a

result of root uptake using soil concentrations and plant-to-soil bioconcentration factors (BCFs) for aboveground produce and forage/browse.

J2-2.5.3.1 Plant-to-Soil Bioconcentration Factor

The plant-to-soil BCFs for forage/browse and garden produce were calculated based on the following equation recommended by the US EPA OSW (2005), adopted from Travis and Arms (1988):

$$\log BCF = 1.588 - 0.578 \times \log K_{ow}$$

Where:

BCF = plant-soil bioconcentration factor for aboveground produce (Table J2-A-31; kg soil/kg plant DW)

log K_{ow} = log of the octanol-water partition coefficient (Table J2-A-16 or Table J2-B-19, 6.0 unitless)

The above equation was derived from experiments conducted on compounds with log K_{ow} values ranging from 1.15 to 9.35. Thus, BCF values for compounds with a log K_{ow} value less than 1.15 should be calculated using a log K_{ow} value of 1.15 and BCF values for compounds with a log K_{ow} greater than 9.35 should be calculated using a log K_{ow} value of 9.35 (US EPA OSW 2005).

Example J2-30 Plant-to-soil bioconcentration factor for benzo(a)pyrene.

$$\log BCF = 1.588 - 0.578 \times 6.0$$

$$BCF = 1.3E-02 \; kg \; soil / kg \; plant \; DW$$

J2-2.5.3.2 Concentrations in Aboveground Forage/Browse Consumed by Wildlife

The following equation was used to predict the chemical concentration in aboveground forage/browse as a result of root uptake (US EPA OSW 2005).

$$\mathrm{Pr} = C_s \times BCF$$

Where:

Pr = chemical concentration in aboveground plant as a result of root uptake (Table J2-A-7; mg/kg DW)

C_s = chemical concentration in soil (Table J2-A-7; 2.1E-06 mg/kg)

BCF = plant-soil bioconcentration factor for aboveground produce (Table J2-A-29; 0.0132 kg soil/kg plant DW)

Example J2-31 Concentration of benzo(a)pyrene in forage/browse as a result of root uptake for the prediction of animal tissue concentrations.

$$\text{Pr} = 2.1E-06 \times 0.0132$$

$$\text{Pr} = 2.7E-08\ mg/kg\ DW$$

J2-2.5.3.3 Concentrations in Aboveground Garden Produce Consumed by Humans

The same equation was used to calculate the chemical concentration in aboveground garden produce, with adjustments made for washing and peeling and the moisture content of the plant.

$$\text{Pr} = C_s \times BCF \times WPF \times (1 - WC)$$

Where:

Pr = chemical concentration in aboveground plant as a result of root uptake (Table J2-B-13; mg/kg WW)

C_s = chemical concentration in soil (Table J2-B-13; 1.3E-06 mg/kg)

BCF = plant-soil bioconcentration factor for aboveground produce (Table J2-B-39; 1.3E-02 kg soil/kg plant DW)

WPF = washing and peeling factor (Table J2-B-37; 1.0; unitless)

WC = water or moisture content of produce (Table J2-B-33; 85%, US EPA OSW 2005)

In the calculation of chemical concentrations in garden produce for human consumption, a washing and peeling factor of 0.85 is typically applied (US EPA OSW 2005). However, in the current assessment no adjustment was made assuming that washing and peeling was not performed.

Example J2-32 Concentration of benzo(a)pyrene in aboveground garden produce as a result of root uptake for the prediction of human exposure.

$$\text{Pr} = 1.3E-06 \times 0.0132 \times 1.0 \times (1 - 0.85)$$

$$\text{Pr} = 2.6E-09\ mg/kg\ WW$$

J2-2.5.4 Belowground Plant Concentrations as a Result of Root Uptake

Chemicals present in soil also can be taken up into edible portions of belowground produce (i.e., root vegetables). The US EPA OSW (2005) provides an equation to predict belowground plant concentrations as a result of root uptake using soil concentrations and plant-to-soil BCFs in root vegetables.

Belowground produce refers to all root vegetables and therefore concentrations derived using this methodology only applied to root vegetable consumption rates. Given that wildlife were

assumed to not consume root vegetables, a belowground forage/browse concentration was not required. The belowground produce concentration for root vegetables was calculated as follows (US EPA OSW 2005):

$$\mathrm{Pr}_{root} = C_s \times BCF \times WPF \times (1 - WC)$$

Where:

Pr_{root} = chemical concentration in belowground produce as a result of root uptake (Table J2-B-13; mg/kg WW)

C_s = chemical concentration in soil (Table J2-B-13; 1.3E-06 mg/kg)

BCF = plant-to-soil bioconcentration factor for belowground plants (Table J2-B-39; 6.05E-02 kg soil/kg plant DW)

WPF = washing and peeling factor (Table J2-B-37; 1.0; unitless)

WC = water or moisture content of root vegetables (Table J2-B-33; 85%, US EPA OSW 2005)

In the calculation of chemical concentrations in garden produce for human consumption, a washing and peeling factor of 0.85 is typically applied (US EPA OSW 2005). However, in the current assessment no adjustment was made assuming that washing and peeling was not performed.

Example J2-33 Concentration of benzo(a)pyrene in root vegetables as a result of root uptake for the prediction of human exposure.

$$\mathrm{Pr}_{root} = 1.3E-06 \times 0.0605 \times 1.0 \times (1 - 0.85)$$

$$\mathrm{Pr}_{root} = 1.2E-08\ mg/kg\ WW$$

J2-2.5.5 Total Chemical Concentration in Leafy Vegetables

The following equation was used to estimate the chemical concentration in above ground produce as a result of direct deposition, vapour uptake, and root uptake.

$$C_{plant} = (Pd + Pv + \mathrm{Pr})$$

Where:

C_{plant} = total chemical concentration in plant

Pd = plant concentration as a result of direct deposition (1.8E-07; Table J2-B-13; mg/kg WW)

Pv = COPC concentration in plant as a result of vapour uptake (2.3E-08 Table J2-B-13; mg/kg WW)

Pr = chemical concentration in aboveground plants as a result of root uptake (2.6E-09; Table J2-B-13; mg/kg WW)

Example J2-34 Concentration of benzo(a)pyrene in aboveground vegetables as a result of direct deposition, vapour uptake and root uptake for the prediction of human exposure.

$$C_{plant} = (1.8E-07 + 2.3E-08 + 2.6E-09)$$

$$C_{plant} = 2.1E-07\ \mu g/d$$

J2-2.5.6 Chemical Concentrations in Labrador Tea

The chemical concentration in Labrador tea was derived using the methods employed for predicting aboveground plant concentrations based on the following uptake mechanisms:

- direct deposition;
- vapour uptake; and
- uptake from soil by roots to above ground portion of plants

The only difference when calculating Labrador tea concentrations is the use of 56% for moisture content in the calculations to convert from dry weight to wet weight.

Example J2-35 Concentration of benzo(a)pyrene in Labrador tea as a result of deposition, vapour uptake and root uptake for the prediction of human exposure.

$$C_{labtea} = 7.5E-09 + 5.4E-07 + 2.3E-08$$

$$C_{labtea} = 7.5E-09\ mg/kg\ WW$$

J2-2.5.7 Chemical Concentrations in Fruit and Wild Berries

The chemical concentration in berries was derived using soil concentrations and plant-to-soil BCFs for aboveground produce.

The following equation was used to predict the chemical concentration in fruits and wild berries as a result of root uptake based on the equation provided by the US EPA OSW (2005) for aboveground produce. Given that wildlife were assumed to not consume berries, a berry concentration was not required for the prediction of animal tissue concentrations. However, berry concentrations were calculated for harvesting by humans. Human receptors were assumed to harvest berries in close proximity to their home or residence.

$$Pb = C_s \times BCF \times WPF \times (1 - WC)$$

Where:

Pb = chemical concentration in fruit or berries as a result of root uptake (Table J2-B-13; mg/kg WW)

C_s = chemical concentration in soil (Table J2-B-13; 1.3E-06 mg/kg)

BCF = plant-to-soil bioconcentration factor for aboveground produce (Table J2-B-39; 1.32E-02 kg soil/kg plant DW)

WPF = washing and peeling factor (Table J2-B-37; 1.0; unitless)

WC = water or moisture content of berries (Table J2-B-33; 81%, site-specific)

In the calculation of chemical concentrations in garden produce for human consumption, a washing and peeling factor of 0.85 is typically applied (US EPA OSW 2005). However, in the current assessment no adjustment was made assuming that washing and peeling was not performed.

Example J2-36 Concentration of benzo(a)pyrene in berries as a result of root uptake for the prediction of human exposure.

$$Pb = 1.3E-06 \times 0.0132 \times 1.0 \times (1 - 0.81)$$

$$Pb = 3.3E-09 \; mg/kg \; WW$$

J2-2.5.8 Chemical Concentrations in Cattail

The chemical concentration in cattail was derived using soil concentrations and plant-to-soil BCFs for belowground plants.

The following equation was used to predict the chemical concentration in cattail as a result of root uptake (US EPA OSW 2005). Given that wildlife were assumed to not consume cattail, a cattail concentration was not required for the prediction of animal tissue concentrations.

$$C_{cattail} = C_s \times BCF \times WPF \times (1 - WC)$$

Where:

$C_{cattail}$ = chemical concentration in cattail as a result of root uptake (Table J2-B-13; mg/kg WW)

C_s = chemical concentration in soil (Table J2-B-13; 3.1E-06 mg/kg)

BCF = plant-to-soil bioconcentration factor for aboveground produce (Table J2-B-39; 6.05E-02 kg soil/kg plant DW)

WPF = washing and peeling factor (Table J2-B-37; 1.0; unitless)

WC = water or moisture content of Cattail (Table J2-B-33; 86%, site-specific)

In the calculation of chemical concentrations in garden produce for human consumption, a washing and peeling factor of 0.85 is typically applied (US EPA OSW 2005). However, in the current assessment no adjustment was made assuming that washing and peeling was not performed.

Example J2-37 Concentration of benzo(a)pyrene in cattail as a result of root uptake for the prediction of human exposure.

$$C_{cattail} = 1.3E-06 \times 0.0605 \times 1.0 \times (1-0.86)$$

$$C_{cattail} = 1.1E-08\ mg/kg\ WW$$

J2-2.5.9 Chemical Concentrations in Aquatic Plants

The chemical concentration in aquatic plants was derived using surface water concentrations and water-to-aquatic plant BCFs. Aquatic plant concentrations were predicted only for the calculation of animal tissue concentrations. The water-to-aquatic plant BCFs were provided by the US EPA OSW (1999).

The following equation was used to predict the chemical concentration in aquatic plants:

$$C_{aqplant} = C_{sw} \times BCF$$

Where:

$C_{aqplant}$ = chemical concentration in aquatic plants (Table J2-A-7; mg/kg DW)

C_{sw} = chemical concentration in surface water (Table J2-A-7; 9.1E-08 mg/L)

BCF = water-to-aquatic plant bioconcentration factor (Table J2-A-31; 1.54E+04 L water/kg plant DW)

Example J2-38 Concentration of benzo(a)pyrene in aquatic plants for the prediction of animal tissue concentrations.

$$C_{aqplant} = 9.1E-08 \times 15{,}353$$

$$C_{aqplant} = 1.4E-03\ mg/kg\ DW$$

J2-2.5.10 Chemical Concentrations in Invertebrates

The chemical concentration in invertebrates was derived using soil concentrations and soil-to-soil invertebrate BCFs. Invertebrate concentrations were predicted only for the calculation of animal tissue concentrations. The soil-to-soil invertebrate BCFs were provided by the US EPA OSW (1999).

The following equation was used to predict the chemical concentration in terrestrial invertebrates:

$$C_{invert} = C_s \times BCF$$

Where:

C_{invert} = chemical concentration in invertebrates (Table J2-A-7; mg/kg DW)

C_s = chemical concentration in soil (Table J2-A-7; 2.1E-06 mg/kg)

BCF = soil-to-soil invertebrate bioconcentration factor (Table J2-A-31; 4.19E-01 kg soil/kg invertebrate DW)

Example J2-39 Concentration of benzo(a)pyrene in terrestrial invertebrates for the prediction of animal tissue concentrations.

$$C_{invert} = 2.1E-06 \times 0.419$$

$$C_{invert} = 8.6E-07\ mg/kg\ DW$$

J2-2.5.11 Chemical Concentrations in Fish

The chemical concentration in fish was derived using predicted surface water concentrations for Christina Lake and surface water-to-fish BCFs. Fish concentrations were predicted only for the calculation of human exposure. The BCF values for benzo(a)pyrene are provided by the ATSDR (1995).

The following equation was used to predict the chemical concentration in fish:

$$C_{fish} = C_{sw} \times BCF$$

Where:

C_{fish} = chemical concentration in fish (Table J2-B-13; mg/kg WW)

C_{sw} = chemical concentration in surface water (Table J2-B-13; 1.5E-16 mg/L)

BCF = surface water-to-fish bioconcentration factor (Table J2-B-39; 55 L water/kg fish WW)

Example J2-40 Concentration of benzo(a)pyrene in fish for the prediction of human exposure.

$$C_{fish} = 3.2E-09 \times 55$$

$$C_{fish} = 1.8E-07\ mg/kg\ WW$$

J2-2.6 Wildlife Exposure Calculations

Tissue concentrations were calculated following the US EPA OSW (2005) methodology. To estimate tissue concentrations, animals were assumed to be exposed to chemicals through consumption of affected soil, water and food. The following sections provide the equations used to calculate the total daily dose of a chemical via the individual exposure pathways for wildlife (moose, grouse and snowshoe hare) and the corresponding tissue concentrations.

J2-2.6.1 Food Ingestion Rates

The food ingestion rate is influenced by a number of factors, such as the metabolic rate and composition of the diet. The rate of food consumption that an animal must achieve to meet its metabolic needs can be calculated by dividing its free-living (or field) metabolic rate (FMR) by the metabolizable energy in its food (US EPA 1993; Nagy 1987).

J2-2.6.1.1 Metabolizable Energy

Metabolizable energy (ME) is the gross energy (GE) in a unit of food consumed minus the energy lost in feces and urine (US EPA 1993). Assimilation efficiency (AE) equals the ratio of metabolizable energy to gross energy, or the fraction of gross energy that is metabolizable (US EPA 1993). Thus, the metabolizable energy for dietary items can be calculated as follows:

$$ME = GE \times AE$$

Where:

ME = metabolizable energy of dietary item (Table J2-A-12; kcal/kg)

GE = gross energy of dietary item (Table J2-A-13; kcal/kg DW)

AE = assimilation efficiency of dietary item (Table J2-A-14; %)

The assimilation efficiency and gross energy values for the different dietary items were provided by the US EPA (1993).

Example J2-41 Metabolizable energy of browse for moose.

$$ME = 4{,}200 \times 0.41$$

$$ME = 1.7E + 03\ kcal / kg$$

J2-2.6.1.2 Free-living Metabolic Rate (Normalized)

Nagy (1987) provides allometric equations to estimate FMRs based on doubly-labelled water measurements of CO_2 production in free-living animals (US EPA 1993). The equations provided by Nagy (1987) are based on the following formula:

$$FMR = \frac{a \times BW^{b}}{4.184\ kJ / kcal}$$

Where:

FMR = free-living metabolic rate (Table J2-A-10; kcal/d)

a = slope of the allometric equation for the FMR (Table J2-A-10; unitless)

BW = body weight (Table J2-A-10; g)

^{b} = y-intercept of the allometric equation for the FMR (Table J2-A-10; unitless)

Nagy et al. (1999) provide a number of slope and y-intercept values for FMRs specific to orders and trophic levels (e.g., rodentia, galliformes, and herbivores). These values were used to estimate the FMR values for each species. Note: The equation used to calculate the FMR for moose does not require the conversion to kcal units; thus the conversion factor of 4.184 kJ/kcal is not needed. However, the conversion factor of 4.184 kJ/kcal is needed in the calculation of the FMR for grouse and snowshoe hare.

Example J2-42 Free-living metabolic rate for moose.

$$FMR = 1.52 \times 4.5E + 05^{0.73}$$

$$FMR = 2.0E + 04\ kcal / d$$

To normalize the FMR to body weight, the FMR was divided by the body weight of the species:

$$NFMR = \frac{FMR}{BW}$$

Where:

NFMR = normalized free-living metabolic rate (Table J2-A-10; kcal/kg bw/d)

FMR = free-living metabolic rate (Table J2-A-10; kcal/d)

BW = body weight (Table J2-A-10; kg)

Example J2-43 Normalized free-living metabolic rate for moose.

$$NFMR = \frac{2.0E + 04}{450}$$

$$NFMR = 4.5E + 01\ kcal / kg\ bw / d$$

J2-2.6.1.3 Ingestion Rates

The estimated ingestion rate for each dietary item was calculated as follows:

$$FIR_i = \frac{FMR \times P_i}{ME_i}$$

Where:

FIR_i = food ingestion rate for the 'i' dietary item (kg/d)

FMR = free-living metabolic rate (Table J2-A-10; kcal/d)

P_i = portion of diet consisting of 'i' dietary item (see Table J2-A-11; %)

ME_i = metabolizable energy of 'i' dietary item (see Table J2-A-12; kcal/kg)

Moose were assumed to consume a diet consisting of 80% browse and 20% aquatic plants.

Example J2-44 Estimated browse ingestion rate for moose.

$$FIR_{browse} = \frac{2.0E+04 \times 0.80}{1{,}722}$$

$$FIR_{browse} = 9.4\ kg/d$$

Example J2-45 Estimated aquatic plant ingestion rate for moose.

$$FIR_{aqplant} = \frac{2.0E+04 \times 0.20}{1{,}763}$$

$$FIR_{aqplant} = 2.3\ kg/d$$

The total ingestion rate for all dietary items was estimated by summing the individual ingestion rates for each dietary item:

$$FIR_{total} = FIR_{invert} + FIR_{browse} + FIR_{aqplant}$$

Where:

FIR_{total} = total food ingestion rate for all dietary items (Table J2-A-9; kg/d)

FIR_{invert} = food ingestion rate for invertebrates (Table J2-A-9; kg/d)

FIR_{browse} = food ingestion rate for browse (Table J2-A-9; kg/d)

$FIR_{aqplant}$ = food ingestion rate for aquatic plants (Table J2-A-9; kg/d)

Example J2-46 Total food ingestion rate for moose.

$$FIR_{total} = 0.0 + 9.44 + 2.31$$

$$FIR_{total} = 1.2E+01\ kg/d$$

To normalize the total food ingestion rate to body weight, the FIR_{total} was divided by the body weight of the species:

$$NFIR_{total} = \frac{FIR_{total}}{BW}$$

Where:

$NFIR_{total}$ = normalized total food ingestion rate (Table J2-A-9; kg food/kg bw/d)

FIR_{total} = total food ingestion rate for all dietary items (Table J2-A-9; kg/d)

BW = body weight (Table J2-A-9; kg)

Example J2-47 Normalized total food ingestion rate for moose.

$$NFIR_{total} = \frac{11.8}{450}$$

$$NFIR_{total} = 2.6E-02\ kg\ \ food/kg\ bw/d$$

J2-2.6.2 Soil Ingestion Rates

The soil ingestion rates were calculated as a percentage of the total estimated food ingestion rate for all dietary items. The percentage of soil in the diet for each of the wildlife species was obtained from the US EPA OSW (2005) and/or Suter et al. (2000).

The soil ingestion rates were calculated as follows:

$$SIR = P_{soil} \times FIR_{total}$$

Where:

SIR = soil ingestion rate (Table J2-A-9; kg/d)

P_{soil} = percent of soil in diet (Table J2-A-9; %)

FIR_{total} = total food ingestion rate for all dietary items (Table J2-A-9; kg/d)

Example J2-48 Soil ingestion rate for moose.

$$SIR = 0.02 \times 11.8$$

$$SIR = 2.4E-01\ kg/d$$

J2-2.6.3 Estimated Daily Intake of Chemicals in Wildlife via All Media

J2-2.6.3.1 Soil Ingestion

The estimated daily intake of a chemical through incidental ingestion of soil by wildlife was calculated by applying the soil ingestion rate to the chemical concentration in the soil.

$$EDI_{soil} = C_s \times SIR$$

Where:

EDI_{soil} = estimated daily intake of chemical in soil (Table J2-A-6; mg/d)

C_s = chemical concentration in surface soil (Table J2-A-7; 2.1E-05 mg/kg)

SIR = soil ingestion rate (Table J2-A-9; kg/d)

Example J2-49 Estimated daily intake of benzo(a)pyrene from ingestion of soil by moose.

$$EDI_{soil} = 2.1E-05 \times 0.24$$

$$EDI_{soil} = 4.8E-06\ mg/d$$

J2-2.6.3.2 Consumption of Browse

The estimated daily intake of a chemical through consumption of browse by wildlife was calculated by applying the browse food ingestion rate to the chemical concentration in vegetation.

$$EDI_{browse} = P_{total} \times FIR_{browse}$$

Where:

EDI_{browse}= estimated daily intake of chemical in browse (Table J2-A-6; mg/d)

P_{total} = chemical concentration in browse from deposition, vapour uptake, and root uptake (Table J2-A-7; 3.2E-05 mg/kg DW)

FIR_{browse}= browse ingestion rate (Table J2-A-9; kg/d)

Example J2-50 Estimated daily intake of benzo(a)pyrene from consumption of browse by moose.

$$EDI_{browse} = 3.2E-05 \times 9.44$$

$$EDI_{browse} = 3.0E-04\ mg/d$$

J2-2.6.3.3 Consumption of Aquatic Plants

The estimated daily intake of a chemical through consumption of aquatic plants by wildlife was calculated by applying the aquatic plant food ingestion rate to the chemical concentration in aquatic plants.

$$EDI_{aqplant} = C_{aqplant} \times FIR_{aqplant}$$

Where:

$EDI_{aqplant}$ = estimated daily intake of chemical in aquatic plants (Table J2-A-6; mg/d)

$C_{aqplant\ t}$ = chemical concentration in aquatic plants (Table J2-A-7; 1.4E-03 mg/kg DW)

$FIR_{aqplant}$ = aquatic plant ingestion rate (Table J2-A-9; 2.3E+01 kg/d)

Example J2-51 Estimated daily intake of benzo(a)pyrene from consumption of aquatic plants by moose.

$$EDI_{aqplant} = 1.4E-03 \times 2.31$$

$$EDI_{aqplant} = 3.2E-03\ mg/d$$

J2-2.6.3.4 Consumption of Invertebrates

The estimated daily intake of a chemical through consumption of invertebrates by wildlife was calculated by applying the invertebrate food ingestion rate to the chemical concentration in invertebrates. It was assumed that moose do not consume invertebrates; therefore ruffed grouse was used as an example for the calculation of invertebrate ingestion.

$$EDI_{invert} = C_{invert} \times FIR_{invert}$$

Where:

EDI_{invert} = estimated daily intake of chemical in invertebrates (Table J2-A-6; mg/d)

C_{invert} = chemical concentration in invertebrates (Table J2-A-7; 8.6E-07 mg/kg DW)

FIR_{invert} = invertebrate ingestion rate (Table J2-A-9; kg/d)

Example J2-52 Estimated daily intake of benzo(a)pyrene from consumption of invertebrates by ruffed grouse.

$$EDI_{invert} = 8.6E-07 \times 5.61E-03$$

$$EDI_{invert} = 4.8E-09\ mg/d$$

J2-2.6.3.5 Ingestion of Water

The estimated daily intake of a chemical through ingestion of surface water by wildlife was calculated by applying the water ingestion rate to the predicted surface water concentration in the unnamed lake.

$$EDI_{water} = C_{sw} \times WIR$$

Where:

EDI_{waterr} = estimated daily intake of chemical in surface water (Table J2-A-6; mg/d)

C_{sw} = chemical concentration in unnamed lake surface water (Table J2-A-7; 9.1E-08 mg/L)

WIR = water ingestion rate (Table J2-A-8; 2.4E+01 L/d)

Example J2-53 Estimated daily intake of benzo(a)pyrene from consumption of surface water by moose.

$$EDI_{water} = 9.1E-08 \times 24.2$$

$$EDI_{water} = 2.2E-06\ mg/d$$

J2-2.6.3.6 Inhalation of Air

The air inhalation rate for wildlife was predicted using allometric equations for birds and mammals, as provided by the US EPA (1993).

Inhalation rate for birds:

$$AIR = 0.4089 \times BW^{0.77}$$

Inhalation rate for mammals:

$$AIR = 0.5458 \times BW^{0.80}$$

Where:

AIR = predicted air inhalation rate (Table J2-A-8; m³/d)

BW = body weight (Table J2-A-8; kg)

Example J2-54 Predicted inhalation rate for moose

$$AIR = 0.5458 \times 450^{0.80}$$

$$AIR = 7.2E+01\ m^3/d$$

The estimated daily intake of a chemical through inhalation of predicted ground-level air concentrations by moose was calculated by applying the air inhalation rate to the predicted air concentration.

$$EDI_{inh} = (C_{air} + C_{dust}) \times AIR \times CF$$

Where:

EDI_{inh} = estimated daily intake of chemical via inhalation (Table J2-A-6; mg/d)

C_{air} = chemical concentration in air (Table J2-A-7; 8.2E-07 µg/m³)

C_{dust} = chemical concentration in dust (Table J2-A-7; 1.6E-11 µg/m³)

AIR = air inhalation rate (Table J2-A-8; m³/d)

CF = conversion factor from µg to mg (0.001 mg/µg)

Example J2-55 Estimated daily intake of benzo(a)pyrene by moose via inhalation.

$$EDI_{inh} = (8.2E-07 + 1.6E-11) \times 72.4 \times 0.001$$

$$EDI_{inh} = 5.9E-08\ mg/d$$

J2-2.6.4 Estimated Total Daily Intake

The estimated daily intake for wildlife and game from all potential pathways of exposure was calculated as follows:

$$EDI_{total} = EDI_{soil} + EDI_{browse} + EDI_{aqplant} + EDI_{invert} + EDI_{water} + EDI_{inh}$$

Where:

EDI_{total} = total estimated daily intake of chemical via all routes of exposure (Table J2-A-6; mg/d)

EDI_{soil} = estimated daily intake of chemical from ingestion of soil (Table J2-A-6; 4.8E-06 mg/d)

EDI_{browse} = estimated daily intake of chemical from consumption of browse (Table J2-A-6; 3.0E-04 mg/d)

$EDI_{aqplant}$ = estimated daily intake of chemical from consumption of aquatic plants (Table J2-A-6; 3.2E-03 mg/d)

EDI_{invert} = estimated daily intake of chemical from consumption of invertebrates (Table J2-A-6; 0.0 mg/d)

EDI_{water} = estimated daily intake of chemical from ingestion of water (Table J2-A-6; 2.2E-06 mg/d)

EDI_{inh} = estimated daily intake of chemical from inhalation of air (Table J2-A-6; 5.9E-08 mg/d)

Example J2-56 Total estimated daily intake of benzo(a)pyrene from all routes of exposure for moose.

$$EDI_{total} = 4.8E-06 + 3.0E-04 + 3.2E-03 + 0 + 2.2E-06 + 5.9E-08$$

$$EDI_{total} = 3.5E-03\ mg/d$$

J2-2.7 Animal Tissue Concentrations

J2-2.7.1 Biotransfer Factors

Biotransfer factors (BTFs) are used to translate an estimated dose of a chemical to a tissue concentration. Biotransfer models have been developed by the Research Triangle Institute (RTI 2005) and were incorporated within the current assessment, as recommended by the US EPA OSW (2005) for organic chemicals. The following equation was developed to predict the transfer rate of the chemical intake into fat tissue.

$$\log BTF = -0.099 \times \log K_{ow}{}^2 + 1.07 \times \log K_{ow} - 3.56$$

Where:

BTF = biotransfer factor ([mg/kg fat] / [mg/d])

$\log K_{ow}$ = log of the octanol-water partition coefficient (Table J2-A-16; 6.0 unitless)

The BTF equation is appropriate for organic chemicals lacking empirical biotransfer data and having a log K_{ow} between -0.67 and 8.2.

Example J2-57 Biotransfer factor for benzo(a)pyrene.

$$\log BTF = -0.099 \times 6.0^2 + 1.07 \times 6.0 - 3.56$$

$$BTF = 0.198\ [mg/kg\ \ fat]/[mg/d]$$

J2-2.7.2 Adjusted Biotransfer Factors

The fat tissue concentration can be converted to a tissue concentration by adjusting the BTF with the fat content of desired tissue (e.g., moose, grouse, snowshoe hare). The fat content for wild game was assumed to be: (Table J2-A-33; US EPA OSW 2005):

- 19% for moose and snowshoe hare
- 14% for ruffed grouse

The BTF was adjusted to account for the amount of fat in the tissue based on the following equation:

$$BTF_a = BTF \times FC$$

Where:

BTF_a = adjusted biotransfer factor for fat content of tissue ([mg/kg tissue] / [mg/d])

BTF = biotransfer factor ([mg/kg fat] / [mg/d])

FC = fat content of tissue (Table J2-A-33; %)

Example J2-58 Adjusted biotransfer factor for benzo(a)pyrene for fat content of meat in moose.

$$BTF_a = 0.198 \times 0.19$$

$$BTF_a = 0.038\,[mg/kg\ tissue]/[mg/d]$$

J2-2.7.3 Metabolism Factors

As provided in the methodology for predicting cattle BTFs (RTI 2005, US EPA OSW 2005), the equation that is used to estimate BTF values might overestimate biotransfer of highly metabolized chemicals. The dataset used to estimate the polynomial relationship between BTFs and K_{ow} is based on anthropogenic chemicals that are persistent (e.g., pesticides) and potentially biomagnify (e.g., pesticides, polychlorinated biphenyls (PCBs), dioxins, and furans). Polycyclic aromatic hydrocarbons (PAHs) were not included in the dataset used to develop the empirical relationship and were identified as potentially highly metabolized chemicals by mammals. Depending on the compound, lipophilicity or K_{ow} measures are not always a good predictor of tissue concentrations (Hofelt et al. 2001).

Evidence strongly suggests that PAHs are extensively metabolized and eliminated. Ramesh et al. (2004), Laurent et al. (2001; 2002), and Grova et al. (2002) investigated the transfer of PAHs in the food chain to goats and pigs. Their studies demonstrate that PAHs are poorly absorbed from diet or readily metabolized and excreted. Hofelt et al. (2001) overcame these limitations for human health assessment by deriving PAH metabolism factors (MF) for use in multipathway hazard assessments. MF values reported for some PAHs are provided in

Table L2-1. The MF values are derived for use with diverse matrices such as milk, beef, chicken, eggs, and pork (Ramesh et al. 2004).

Table L2-1 Metabolism Factors for PAHs

Chemical	Animal Model	Metabolism Factor (MF)
Benz(a)anthracene	**Rat**	**0.001**
Benzo(a)pyrene	**Mouse**	**0.004**
Pyrene	**Rat**	**0.003**

Hofelt et al. (2001) recommends a MF of 0.01 for PAHs. The MF is applied to the adjusted BTF for fat content of tissue to derive an adjusted BTF for metabolism, as follows:

$$BTF_{adj} = BTF_a \times MF$$

Where:

BTF_{adj} = adjusted biotransfer factor for metabolism (Table J2-A-32; [mg/kg tissue] / [mg/d])

BTF_a = adjusted biotransfer factor for fat content of tissue ([mg/kg tissue] / [mg/d])

MF = metabolism factor (Table J2-A-34; PAHs=0.01, VOCs=1.0, unitless)

Example J2-59 Adjusted biotransfer factor for benzo(a)pyrene metabolism in moose.

$$BTF_{adj} = 0.038 \times 0.01$$

$$BTF_{adj} = 0.00038\ [mg / kg\ tissue] / [mg / d]$$

J2-2.7.4 Tissue Concentrations

Chemical concentrations in animal meat were predicted based on the following equation:

$$C_{animal} = BTF_{adj} \times EDI_{total}$$

Where:

C_{animal} = chemical concentration in animal meat (Table J2-A-6; mg/kg WW)

BTF_{adj} = adjusted biotransfer factor for metabolism (Table J2-A-32; 3.8E-04 [mg/kg tissue] / [mg/d])

EDI_{total} = total estimated daily intake of chemical via all routes of exposure (Table J2-A-6; 3.5E-03 mg/d)

Example J2-60 Predicted concentration of benzo(a)pyrene in moose meat

$$C_{moose} = 3.8E-04 \times 3.5E-03$$

$$C_{moose} = 1.3E-06\ mg/kg\ WW$$

Similar methods were applied to the calculation of grouse and snowshoe hare concentrations.

J2-3.0 HUMAN EXPOSURE ESTIMATES

J2-3.1 Ingestion of Soil (Incidental)

The following equation was used to estimate human exposure via incidental ingestion of soil. Soil ingestion rates were based on recommendations from Health Canada (2004).

$$EDI_{soil} = C_s \times SIR$$

Where:

EDI_{soil} = estimated daily intake of chemical via ingestion of soil (Table J2-B-12; µg/d)

C_s = chemical concentration in surface soil (Table J2-B-13; 1.3E-05 mg/kg)

SIR = incidental soil ingestion rate (Table J2-B-15; 2.0E-02 g/d)

Example J2-61 Estimated daily intake of benzo(a)pyrene by an adult resident from incidental ingestion of soil

$$EDI_{soil} = 1.3E-05 \times 0.02$$

$$EDI_{soil} = 2.6E-07\ \mu g/d$$

J2-3.2 Ingestion of Drinking Water

It was assumed that residents consumed local raw surface water from Christina Lake. Water ingestion rates were based on recommendations from Health Canada (2004) and exposures were based on the following equation:

$$EDI_{water} = C_{sw} \times WIR \times CF$$

Where:

EDI_{water} = estimated daily intake of chemical via ingestion of water (Table J2-B-12; µg/d)

C_{sw} = chemical concentration in surface water (Table J2-B-13; 3.3E-09 mg/L)

WIR = water ingestion rate (Table J2-B-15; 1.5 L/d)

CF = conversion factor from mg to µg (1,000 µg/mg)

Example J2-62 Estimated daily intake of benzo(a)pyrene by an adult resident from ingestion of surface water

$$EDI_{water} = 3.3E-09 \times 1.5 \times 1{,}000$$

$$EDI_{water} = 4.9E-06\ \mu g/d$$

J2-3.3 Inhalation of Dust

The following equation was used to estimate human exposure via inhalation of dust. Air inhalation rates were based on recommendations from Health Canada (2004).

$$EDI_{dust} = C_{dust} \times AIR$$

Where:

EDI_{dust} = estimated daily intake of chemical via inhalation of dust (Table J2-B-12; µg/d)

C_{dust} = chemical concentration in dust (Table J2-B-13; 9.9E-12 µg/m³)

AIR = air inhalation rate (Table J2-B-15; 15.8 m³/d)

Example J2-63 Estimated daily intake of benzo(a)pyrene by an adult resident from inhalation of dust

$$EDI_{dust} = 9.9E-12 \times 15.8$$

$$EDI_{dust} = 1.6E-10\ \mu g/d$$

J2-3.4 Ingestion of Plants

J2-3.4.1 Leafy Vegetables

The following equation was used to estimate human exposure via consumption of leafy vegetables or wild leafy plants. Consumption rates were obtained from Health Canada (2004).

$$EDI_{plant} = C_{plant} \times IR_{plant}$$

Where:

EDI_{plant} = estimated daily intake of chemical via consumption of aboveground leafy plants (Table J2-B-12; µg/d)

C_{plant} = total chemical concentration in leafy plant (Table J2-B-13; 2.1E-07)

IR_{plant} = leafy plant ingestion rate (Table J2-B-15; 137 g/d)

Example J2-64 Estimated daily intake of benzo(a)pyrene by an adult resident from consumption of aboveground leafy plants

$$EDI_{plant} = 2.1E-07 \times 137$$

$$EDI_{plant} = 2.9E-05\ \mu g/d$$

J2-3.4.2 Root Vegetables

The following equations were used to estimate human exposure via consumption of root vegetables. Consumption rates were obtained from Health Canada (2004).

The estimated exposure from consumption of root vegetables is:

$$EDI_{root} = \Pr_{root} \times IR_{root}$$

Where:

EDI_{root} = estimated daily intake of chemical via consumption of root vegetables (Table J2-B-12; µg/d)

Pr_{root} = chemical concentration in root vegetables from root uptake (Table J2-B-13; 1.2E-08 mg/kg WW)

IR_{root} = root vegetable ingestion rate (Table J2-B-15; 188 g/d)

Example J2-65 Estimated daily intake of benzo(a)pyrene by an adult resident from consumption of root vegetables

$$EDI_{root} = 1.2E-08 \times 188$$

$$EDI_{root} = 2.2E-06\ \mu g/d$$

J2-3.4.3 Fruit and Wild Berries

The following equation was used to estimate human exposure via consumption of fruit and wild berries. Consumption rates were obtained from Health Canada (1994).

$$EDI_{berry} = Pb \times IR_{berry}$$

Where:

EDI_{berry} = estimated daily intake of chemical via consumption of fruit and berries (Table J2-B-12; µg/d)

Pb = chemical concentration in fruit and berries from root uptake (Table J2-B-13; 3.3E-09 mg/kg WW)

IR_{berry} = fruit and berry ingestion rate (Table J2-B-15; 45 g/d), from Health Canada (1994)

Example J2-66 Estimated daily intake of benzo(a)pyrene by an adult resident from consumption of berries

$$EDI_{berry} = 3.3E-09 \times 45$$

$$EDI_{berry} = 1.5E-07\ \mu g/d$$

J2-3.4.4 Labrador Tea

The following equation was used to estimate human exposure via consumption of Labrador tea. Consumption rates were obtained from Wein (1989).

$$EDI_{labtea} = C_{labtea} \times IR_{labtea}$$

Where:

EDI_{labtea}= estimated daily intake of chemical via consumption of Labrador tea (Table J2-B-12; µg/d)

C_{labtea} = chemical concentration in Labrador tea (Table J2-B-13; 7.5E-09 mg/kg WW)

IR_{labtea}= Labrador tea ingestion rate (Table J2-B-15; 3 g/d)

Example J2-67 Estimated daily intake of benzo(a)pyrene by an adult resident from consumption of Labrador tea.

$$EDI_{labtea} = 7.5E-09 \times 3$$

$$EDI_{labtea} = 2.3E-08\ \mu g/d$$

J2-3.4.5 Cattail

The following equation was used to estimate human exposure via consumption of cattail. Consumption rates were obtained from Wein et al. (1991).

$$EDI_{cattail} = C_{cattail} \times IR_{cattail}$$

Where:

$EDI_{cattail}$ = estimated daily intake of chemical via consumption of cattail (Table J2-B-12; µg/d)

$C_{cattail}$ = chemical concentration in cattail (Table J2-B-13; 1.1E-08 mg/kg WW)

$IR_{cattail}$ = cattail ingestion rate (Table J2-B-15; 3 g/d)

Example J2-68 Estimated daily intake of benzo(a)pyrene by an adult resident from consumption of cattail

$$EDI_{cattail} = 1.1E-08 \times 3$$

$$EDI_{cattail} = 3.3E-08\ \mu g/d$$

J2-3.5 Ingestion of Wild Game and Fish

Wild game consumption rates for moose, grouse and snowshoe hare for the residents were based on Health Canada (2004) and Wein et al. (1991). To determine the consumption rates specific to moose, snowshoe hare and ruffed grouse, Health Canada's food ingestion rates for Canadian First Nations populations were used in combination with the frequency of consumption reported for three categories of wild game (i.e., large mammals, small mammals and upland birds) by Wein et al. (1991). Food consumption patterns of Aboriginal (First Nations and Métis) Canadians near Wood Buffalo National Park (WBNP) were obtained by Wein et al. (1991) by repeated 24 hour food recall surveys: two surveys were completed between late August and mid-November 1986; and, two surveys were completed between late April and mid-July 1987 (Wein et al. 1991). One hundred and seventy-eight individuals over 12 years of age were interviewed. According to Wein et al. (1991), large mammals constituted 76% of the wild game consumed by the individuals interviewed, small mammals constituted 16%, and upland birds constituted 8%. From this, it was assumed that residential adults would consume 205 grams of moose per day, 43 grams of snowshoe hare per day, and 22 grams of ruffed grouse per day for a total of 270 grams of wild game per day.

Fish consumption rates were obtained from Health Canada (2007) for the residents.

Table J2-B-15 lists all consumption rates used in the assessment of human exposure for the residents.

The following equation was used to estimate human exposure via consumption of fish or wild game.

$$EDI_{animal} = C_{animal} \times IR_{animal}$$

Where:

EDI_{animal} = estimated daily intake of chemical via consumption of fish or wild game (Table J2-B-12; µg/d)

C_{animal} = chemical concentration in animal tissue (Table J2-B-13; mg/kg WW)

IR_{animal} = fish or wild game ingestion rate (Table J2-B-15; g/d)

Example J2-69 **Estimated daily intake of benzo(a)pyrene by an adult resident from consumption of moose**

$$EDI_{moose} = 1.8E-09 \times 205$$

$$EDI_{moose} = 3.8E-07\ \mu g/d$$

Example J2-70 **Estimated daily intake of benzo(a)pyrene by an adult resident from consumption of ruffed grouse**

$$EDI_{grouse} = 3.06E-11 \times 43$$

$$EDI_{grouse} = 1.3E-09\ \mu g/d$$

Example J2-71 **Estimated daily intake of benzo(a)pyrene by an adult resident from consumption of snowshoe hare**

$$EDI_{hare} = 2.90E-11 \times 22$$

$$EDI_{hare} = 6.3E-10\ \mu g/d$$

Example J2-72 **Estimated daily intake of benzo(a)pyrene by an adult resident from consumption of fish**

$$EDI_{fish} = 1.8E-07 \times 40$$

$$EDI_{fish} = 7.2E-06\ \mu g/d$$

J2-3.6 Swimming Exposure Through Dermal and Ingestion Pathways

J2-3.6.1 Dermal Exposure to Surface Water

The following equation was used to estimate dermal exposure from swimming based on recommendations from US EPA (2004) and Health Canada (2004).

$$EDI_{derm+swim} = C_{sw} \times Kp \times SEF \times SED \times SAT \times CF1 \times CF2$$

Where:

$EDI_{derm+swim}$ = estimated daily intake of chemical from dermal contact with surface water (µg/d)

C_{sw} = chemical concentration in local surface water (Christina Lake) (Table J2-B-13; 3.3E-09 mg/L)

Kp = dermal permeability coefficient in water (Table J2-B-26; 0.561 cm/hr)

SEF = swim exposure frequency Table J2-B-15; 1.0 hr/d)

SED = swim exposure duration (Table J2-B-15; 0.255 d/d per yr)

SAT = surface area total (Table J2-B-15; 9,110 cm²)

CF1 = conversion factor from mg to µg (1,000 µg/mg)

CF2 = conversion factor from L to cm³ (0.001 L/cm³)

Example J2-73 Estimated daily intake of benzo(a)pyrene by an adult resident from dermal uptake during swimming

$$EDI_{derm+swim} = 3.3E-09 \times 0.561 \times 1 \times 0.255 \times 9{,}110 \times 1{,}000 \times 0.001$$

$$EDI_{derm+swim} = 4.3E-06\ \mu g/d$$

J2-3.6.2 Incidental Ingestion of Surface Water during Swimming

The following equation was used to estimate ingestion exposure from swimming based on recommendations from US EPA (2004) and Health Canada (2004).

$$EDI_{ing+swim} = C_{sw} \times SED \times SWIR \times CF1$$

Where:

$EDI_{ing+swim}$ = estimated daily intake of chemical from ingestion of surface water during swimming (µg/d)

C_{sw} = chemical concentration in local surface water (Table J2-B-13; 3.3E-09 mg/L)

SED = swim exposure duration (Table J2-B-15; 0.255 d/d per yr)

SWIR = swimming ingestion rate (Table J2-B-15; 0.025 L/d)

CF1 = conversion factor from mg to µg (1,000 µg/mg)

Example J2-74 Estimated daily intake of benzo(a)pyrene by an adult resident from ingestion of surface water during swimming

$$EDI_{ing+swim} = 3.3E-09 \times 0.255 \times 0.025 \times 1{,}000$$

$$EDI_{ing+swim} = 2.1E-08\ \mu g/d$$

J2-3.6.3 Total Exposure to Surface Water during Swimming

The following equation was used to estimate total ingestion and dermal exposure from swimming.

$$EDI_{tot\_swim} = EDI_{derm+swim} + EDI_{ing+swim}$$

Where:

EDI_{tot_swim} = estimated daily intake of chemical from ingestion of and dermal contact with surface water during swimming (Table J2-B-12; µg/d)

$EDI_{derm+swim}$ = estimated daily intake of chemical from dermal contact with surface water during swimming (4.3E-06 µg/d)

$EDI_{ing+swim}$ = estimated daily intake of chemical from ingestion of surface water during swimming (2.1E-08 µg/d)

Example J2-75 Estimated daily intake of benzo(a)pyrene by an adult resident from ingestion of and dermal contact with surface water during swimming.

$$EDI_{tot\_swim} = 4.3E-06 + 2.1E-08$$

$$EDI_{tot\_swim} = 4.3E-06\ \mu g/d$$

J2-3.7 Dermal Exposures

J2-3.7.1 Dermal Exposures from Soils

Potential dermal exposure was estimated by applying soil loading rates to exposed skin, skin surface areas, and dermal absorption factors to measured or predicted soil concentrations. Dermal exposures were estimated separately for hands only and for surfaces other than hands (e.g., arms and legs).

J2-3.7.1.1 Dermal Exposure to Hands

The following equation was used to estimate dermal exposure for hands only. Dermal exposures were based on recommendations from Health Canada (2004).

$$EDI_{dermal\_h} = C_s \times SAH \times SLH \times RAF_{dermal}$$

Where:

EDI_{dermal_h} = estimated daily intake of chemical from dermal contact of hands with soil (Table J2-B-12; µg/d)

C_s = chemical concentration in surface soil (Table J2-B-13; 1.3E-05 mg/kg)

SAH = skin surface area of hands (Table J2-B-15; 890 cm²)

SLH = soil loading rate to exposed skin on hands (Table J2-B-15; 1.0E-04 g/cm²/event)

RAF_{dermal} = relative dermal absorption factor (Table J2-B-28; 20%)

Example J2-76 Estimated daily intake of benzo(a)pyrene by an adult resident from dermal exposure to soil with hands only.

$$EDI_{dermal\_h} = 1.3E-05 \times 890 \times 0.0001 \times 0.20$$

$$EDI_{dermal\_h} = 2.3E-07\ \mu g/d$$

J2-3.7.1.2 Dermal Exposure to Surfaces Other than Hands

The following equation was used to estimate dermal exposure for surfaces other than hands. Dermal exposures were based on recommendations from Health Canada (2004).

$$EDI_{dermal\_o} = C_s \times SAO \times SLO \times RAF_{dermal}$$

Where:

EDI_{dermal_o} = estimated daily intake of chemical from dermal contact of surfaces other than hands with soil (Table J2-B-12; µg/d)

C_s = chemical concentration in surface soil (Table J2-B-13; 1.3E-05 mg/kg)

SAO = skin surface area of upper and lower arms and legs (Table J2-B-15; 8,220 cm²)

SLH = soil loading rate to exposed skin on surfaces other than hands (Table J2-B-15; 1.0E-05 g/cm²/event)

RAF_{dermal} = relative dermal absorption factor (Table J2-B-28; 20%)

Example J2-77 Estimated daily intake of benzo(a)pyrene by an adult resident from dermal exposure to soil with surfaces other than hands.

$$EDI_{dermal\_o} = 1.3E-05 \times 8{,}220 \times 0.00001 \times 0.20$$

$$EDI_{dermal\_o} = 2.1E-07\ \mu g/d$$

J2-3.8 Ingestion of Breast Milk by Infants

The potential health effects associated with the ingestion of the chemical-affected breast milk by nursing infants was considered in the current assessment. The estimated exposure from consumption of breast milk was calculated as the product of the breast milk consumption rate and predicted chemical concentration in breast milk. The equations used to predict the chemical concentration in breast milk are described in the following sections. The multiple pathway exposure model assumed that infants (i.e., 0 to 6 months of age) derived their nutrients entirely from breast milk, and not from solid foods derived from the study area (e.g., traditional plants and game meat).

J2-3.8.1 Breast Milk Biotransfer Factor

The BTF for breast milk was used to convert the adult mother's total predicted exposure to a chemical concentration in her breast milk. The maximum fraction of the chemical expected to bioaccumulate was calculated using the following approach (McKone 1992):

$$BTF_{BM} = 2.0E-07 \times K_{ow}$$

Where:

BTF_{BM} = breast milk biotransfer factor (Table J2-B-40; [µg/kg milk] / [µg/d intake])

K_{ow} = octanol-water partition coefficient (Table J2-B-18; 1.0E+06 unitless)

Example J2-78 Breast milk biotransfer factor for benzo(a)pyrene for an infant resident.

$$BTF_{BM} = 2.0E-07 \times 1.0E+06$$

$$BTF_{BM} = 0.20\ [\mu g / kg\ milk] / [\mu g / d\ intake]$$

J2-3.8.2 Chemical Concentration in Breast Milk

The predicted breast milk concentration was calculated as follows:

$$C_{BM} = \frac{EDI_{mother} \times BW_{mother} \times BTF_{BM}}{CF}$$

Where:

C_{BM} = predicted concentration of chemical in breast milk (µg/g milk)

EDI_{mother} = mother's total daily exposure to chemical via all routes (Table J2-B-12; 6.9E-07 µg/kg/d)

BW_{mother} = body weight of mother (Table J2-B-15; 70.7 kg)

BTF_{BM} = breast milk biotransfer factor (Table J2-B-40; 0.20 [µg/kg milk] / [µg/d intake])

CF = conversion factor from kg to g (1,000 g/kg)

Example J2-79 Concentration of benzo(a)pyrene in breast milk for an infant resident.

$$C_{BM} = \frac{6.9E-07 \times 70.7 \times 0.20}{1{,}000}$$

$$C_{BM} = 9.8E-09\ \mu g / g\ milk$$

J2-3.8.3 Breast Milk Consumption

The estimated exposure from consumption of breast milk for infants was calculated as follows:

$$EDI_{BM} = C_{BM} \times IR_{BM}$$

Where:

EDI_{BM} = estimated daily intake of chemical from consumption of breast milk (Table J2-B-12; µg/d)

C_{BM} = concentration of chemical in breast milk (9.8E-09 µg/g milk)

IR_{BM} = breast milk ingestion rate (664 g/d; O'Connor and Richardson 1997)

As only infants were assumed to consume breast milk, the sample calculations below is based on a residential infant.

Example J2-80 Estimated daily intake of benzo(a)pyrene for an infant resident from breast milk consumption.

$$EDI_{BM} = 9.8E-09 \times 664$$

$$EDI_{BM} = 6.5E-06\ \mu g/d\ milk$$

J2-3.9 Total Human Exposure

Total exposure was calculated by summing the individual exposures from each medium (i.e., soil, water, dust, and vegetation) for all relevant exposure pathways on a per chemical and per life stage basis:

$$EDI_{total} = EDI_{soil} + EDI_{water} + EDI_{dust} + EDI_{food} + EDI_{tot\_swim} + EDI_{dermal\_h} + EDI_{dermal\_o} + EDI_{BM}$$

Where:

EDI_{total} = total estimated daily intake of chemical via all routes (Table J2-B-12; µg/d)

EDI_{soil} = estimated daily intake of chemical from soil ingestion (Table J2-B-12; 2.6E-07 µg/d)

EDI_{water} = estimated daily intake of chemical from ingestion of water (Table J2-B-12; 4.9E-06 µg/d)

EDI_{dust} = estimated daily intake of chemical from dust inhalation (Table J2-B-12; 1.6E-10 µg/d)

EDI_{food} = estimated daily intake of chemical from consumption of all food types (Table J2-B-12; 3.9E-05 µg/d [sum of leafy plants, root vegetables, berries, Labrador tea, cattail, fish, moose, grouse, and snowshoe hare])

EDI_{tot_swim} = estimated daily intake of chemical from dermal contact and incidental ingestion of surface water during swimming (Table J2-B-12; 4.3E-06 µg/d)

EDI_{dermal_h} = estimated daily intake of chemical from dermal contact of hands with soil (Table J2-B-12; 2.3E-07 µg/d)

EDI_{dermal_o} = estimated daily intake of chemical from dermal contact of surfaces other than hands with soil (Table J2-B-12; 2.1E-07 µg/d)

EDI_{BM} = estimated daily intake of chemical from breast milk consumption (Table J2-B-12; 0.0 µg/d)

Example J2-81 **Total estimated daily intake of benzo(a)pyrene for an adult resident from all routes of exposure.**

$$EDI_{total} = 2.6E-07 + 4.9E-06 + 1.6E-10 + 3.9E-05 + 4.3E-06 + 2.3E-07 + 2.1E-07 + 0$$

$$EDI_{total} = 4.9E-05 \mu g/d$$

The total estimated daily intake was normalized to body weight as follows:

$$EDI_{total\_BW} = \frac{EDI_{total}}{BW}$$

Where:

EDI_{total_BW} = total estimated daily intake of chemical via all routes adjusted to body weight (Table J2-B-12; µg/kg bw/d)

EDI_{total} = total estimated daily intake of chemical via all routes (Table J2-B-12; 4.9E-05 µg/d)

BW = body weight (Table J2-B-15; 70.7 kg)

Example J2-82 **Total estimated daily intake of benzo(a)pyrene for an adult resident from all routes of exposure adjusted to body weight .**

$$EDI_{total\_BW} = \frac{4.9E-05}{70.7}$$

$$EDI_{total\_BW} = 6.9E-07 \ \mu g/kg\ bw/d$$

J2-4.0 HUMAN HAZARD CALCULATIONS

Risk quotients (RQs) for non–carcinogens and incremental lifetime cancer hazards (ILCRs) for carcinogens were estimated using the following equations and the calculated exposure estimates.

J2-4.1 Non-Carcinogens

The following equation was used to calculate the hazard quotients for non–carcinogens:

$$RQ_i = \frac{EDI_{total\_BW}}{RfD}$$

Where:

RQ_i = risk quotient of chemical for the 'i' lifestage of the residents (Table J2-B-3; unitless)

EDI_{total_BW} = total estimated daily intake of chemical via all routes adjusted to body weight for the 'i' lifestage (Table J2-B-12; µg/kg bw/d)

RfD = chemical-specific reference dose (Table J2-B-14; µg/kg bw/d)

The maximum RQ value of all the life stages (i.e., infant, toddler, child, adolescent, and adult) was presented in the HHRA report for non-carcinogens. Given that benzo(a)pyrene was evaluated as a carcinogen in the current assessment, the aromatic C_9-C_{16} group was used in the sample calculation below. The toddler stage had the highest EDI of all the life stages for the aromatic C_9-C_{16} group .

Example J2-83 Risk quotient for the aromatic C_9-C_{16} group for the "i" lifestage of the resident in the project alone assessment.

$$RQ_i = \frac{3.0E-01}{40}$$

$$RQ_i = 7.5E-03$$

J2-4.2 Carcinogens

The following equation was used to calculate the lifetime cancer risks and incremental lifetime cancer risks for carcinogens.

$$ILCR_i = \left(\frac{EDI_{total\_BW}}{RsD}\right) \times LAF_i$$

Where:

$ILCR_i$ = incremental lifetime cancer risk for the 'i' lifestage of the residents (Table J2-B-3; unitless)

EDI_{total_BW} = total estimated daily intake of chemical via all routes adjusted to body weight for the 'i' lifestage (Table J2-B-12; 6.9E-07 µg/kg bw/d)

RsD = chemical-specific risk-specific dose (Table J2-B-14; 0.0014 µg/kg bw/d)

LAF_i = life adjustment factor for the 'i' lifestage (Table J2-B-15; 0.737 yr-lifestage/yr-lifespan)

Example J2-84 Incremental lifetime cancer risk from benzo(a)pyrene for an adult resident

$$ILCR_i = \left(\frac{6.9E-07}{0.0014}\right) \times 0.737$$

$$ILCR_i = 3.6E-04$$

For carcinogens, cancer risks were presented for lifetime exposure using a composite receptor. The cancer risk for the composite receptor was calculated by summing the cancer risks for each life stage.

$$ILCR_{composite} = \sum ILCR_i$$

$$ILCR_{composite} = ILCR_{\text{inf ant}} + ILCR_{toddler} + ILCR_{child} + ILCR_{adolescent} + ILCR_{adult}$$

Where:

$ILCR_{composite}$ = incremental lifetime cancer risk for a composite receptor (Table J2-B-3; unitless)

$ILCR_i$ = lifetime cancer risk or incremental lifetime cancer risk for the 'i' lifestage (Table J2-B-3; unitless)

Example J2-85 Incremental lifetime cancer risk from benzo(a)pyrene for a composite resident

$$ILCR_{composite} = 4.9E-06 + 6.1E-05 + 6.9E-05 + 5.4E-05 + 3.6E-04$$

$$ILCR_{composite} = 5.5E-04$$

The calculation above provides estimated carcinogenic risks for a life time of exposure.

J2-5.0 REFERENCES/LITERATURE CITED

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