APPENDIX A - HUMAN HEALTH RISK EQUATIONS

LAND USE SCENARIOS

The five land use scenarios considered in SADA are: future unrestricted industrial, residential, recreational, excavation, and agricultural exposures. The purpose of evaluating future land use scenarios as part of the risk assessment is to establish whether remedial action is necessary for alternate land uses by determining if the cumulative risk or hazard index from the source areas could exceed levels of concern. The future land use scenarios are based on the assumption that unrestricted industrial workers, residents, farmers, or recreational users of the area could be exposed. Current contaminant concentrations are used for the on-site assessment of future exposure. This represents a maximum exposure to contaminants in the area and will serve to define the potential human health risks that would exist if residential, unrestricted industrial, or recreational occupation were to begin within a short time frame.

Under the industrial scenario, industrial workers are expected to be routinely exposed to contaminated media within a commercial area or industrial site. The future industrial scenario is evaluated using industrial default occupational values provided by EPA. Pathways are evaluated for exposures to surface soil, sediment, and surface water. The exposures are based on the potential for the use of heavy equipment and related traffic in and around the contaminated soil and sediment in an unrestricted industrial scenario. Soils and sediment could be disturbed, thereby producing particulate emissions which could then be inhaled by the industrial worker. It should be noted that the assumptions and default parameters for the industrial land use scenario do not reflect the use of protective clothing or other safety precautions. The drinking water pathway to surface water (based on 1 L/day ingestion) is also evaluated for future industrial land use, although it is unlikely.

Under the residential land use scenario, future residents are expected to be in frequent, repeated contact with contaminated media. The assumptions in this scenario account for daily exposure over the long term and generally result in the highest potential exposures and risk. Exposure is calculated for a lifetime, which includes exposures for the receptor as both child and adult. Pathways are evaluated for exposures to surface soil, sediment, and surface water. In an industrial area where redevelopment for homes is not feasible now or in the foreseeable future, future land use planning scenarios would be more accurately reflected as industrial rather than residential. However, to provide a conservative assessment of risk, a residential land use scenario is assumed as one of the potential receptors. Consequently, appropriate default parameters and equations for residential land use are evaluated.

The recreational scenario addresses exposure to children and adults who spend a limited amount of time at or near the site while engaging in outdoor activities. The recreational land use scenario is also referred to as the trespasser or site visitor scenario. Pathways are evaluated for exposures to surface soil, sediment, and surface water.

For the excavation scenario, exposure to soil and sediment for a short period are considered to be appropriate. The exposure routes for soil and sediment for the excavation worker are: incidental ingestion, inhalation of emitted particulates and vapors, dermal contact, and external exposure to ionizing radiation.

The agricultural scenario assumes a resident is exposed to homegrown farm products. Exposure routes considered in addition to the residential pathways include the consumption of vegetables, the consumption of whole milk, and the consumption of beef.

SOIL/ SEDIMENT EXPOSURE PATHWAYS

Exposure pathways evaluated for soil and sediment include incidental ingestion, inhalation, dermal contact, external exposure, and agricultural pathways. Table 1 summarizes the pathways that can be evaluated for each scenario in SADA.

Table 1. Soil/Sediment Exposure Pathways by Scenario

Landuse/Pathway	Residential	Industrial	Recreational	Excavation	Agricultural
Incidental Ingestion	Yes	Yes	Yes	Yes	Yes
Inhalation	Yes	Yes	Yes	Yes	Yes
Dermal Contact	Yes	Yes	Yes	Yes	Yes
External	Yes	Yes	Yes	Yes	Yes
Vegetable Ingestion	Yes	No	No	No	Yes
Beef Ingestion	Yes	No	No	No	Yes
Milk Ingestion	Yes	No	No	No	Yes

Incidental Soil/Sediment Ingestion

The incidental ingestion of soil is a potentially significant source of exposure. Equation 1(non-radionuclides), Equation 2 (radionuclides), and Table 2 present the exposure variables for the soil/sediment ingestion pathway for the residential, industrial, recreational, and agricultural scenarios. The potential for exposure to children is greater due to behavioral patterns present during childhood. The higher value for children under the non-industrial scenarios are based on fecal tracer studies and account for the ingestion of both indoor and outdoor dust.

$$Nonrad\ Intake_{ing} = \frac{C_{sn}\, CF_1\, EF\ FI\ ED\ IR_{a,c}}{CF_2\, BW_{a,c}\, AT} \qquad (1)$$

$$Rad\ Intake_{ing} = C_{sr}\, CF_3\, EF\ FI\ ED\ IR \qquad (2)$$

Table 2. Soil/Sediment Ingestion Parameters

Parameter	Units	Residential	Industrial	Recreational	Excavation	Agricultural
Non-radionuclide chemical concentration in soil = C_{sn}	mg/kg	Chemical-specific	Chemical-specific	Chemical-specific	Chemical-specific	Chemical-specific

Radionuclide chemical concentration in soil = **C_{sr}**	pCi/g	Chemical-specific	Chemical-specific	Chemical-specific	Chemical-specific	Chemical-specific
Conversion factor = **CF_1**	kg/mg	10^{-6}	10^{-6}	10^{-6}	10^{-6}	10^{-6}
Exposure frequency = **EF**	days/yr	350 (EPA 1989a)	250 (EPA 1991a)	40 (EPA 1992)	20	350 (EPA 1989a)
Fraction ingested = **FI**	unitless	1	1	1	1	1
Exposure duration = **ED**	years	24 (adult) 6 (child) (EPA 1989a)	25 (adult) (EPA 1991a)	24 (adult) 6 (child) (EPA 1989a)	1	24 (adult) 6 (child) (EPA 1989a)
Conversion factor = **CF_8**	g/mg	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}
Ingestion rate of soil = **IR**	mg/d	100 (adult) 200 (child) (EPA 1989a)	200 (adult) (EPA 1989a)	100 (adult) 200 (child) (EPA 1989a)	480 (construction worker) (EPA 1991b)	100 (adult) 200 (child) (EPA 1989a)
Body weight = **BW**	kg	70 (adult) 15 (child) (EPA 1991a)	70 (adult) (EPA 1991a)	70 (adult) 15 (child) (EPA 1991a)	70 (adult) (EPA 1991a)	70 (adult) 15 (child) (EPA 1991a)
Conversion Factor == **CF_2**	days/yr	365	365	365	365	365
Lifetime = **LT**	years	70 (EPA 1989a)	70 (EPA 1989a)	70 (EPA 1989a)	70 (EPA 1989a)	70 (EPA 1989a)
Averaging time = **AT**	years	LT (carcinogen) ED (noncarcinogen)	LT (carcinogen) ED (noncarcinogen)	LT (carcinogen) ED (noncarcinogen)	LT (carcinogen) ED (noncarcinogen)	LT (carcinogen) ED (noncarcinogen)

Soil/Sediment Inhalation

Equation 3 (non-radionuclides), equation 4 (radionuclides), and Table 3 present the exposure variables for the soil/sediment inhalation pathway for the residential, industrial, recreational, and agricultural scenarios. The particulate emission factor (PEF) is represented by the term that includes V, U_m/U_t, F(x), Q/C, and CF_3. The default PEF in SADA is 1.32E+9 (EPA 1996). The 1/VF term is only present if the contaminant is a volatile.

$$Nonrad\ Intake_{ink} = \frac{C_{sn}\, EF\, ED \left(\frac{1}{VF} + \frac{0.036\,(1-V)\,(U_m/U_t)^3\, F(x)}{(Q/C)\, CF_3} \right) IR_{air}}{CF_2\, BW\, AT} \qquad (3)$$

$$Rad\ Intake_{ink} = C_{sr}\, CF_5\, EF\, ED \left(\frac{1}{VF} + \frac{0.036\,(1-V)\,(U_m/U_t)^3\,F(x)}{(Q/C)\,CF_3} \right) IR_{air} \quad (4)$$

Table 3. Soil/Sediment Inhalation Parameters

Parameter	Units	Residential	Industrial	Recreational	Excavation	Agricultural
Non-radionuclide chemical concentration in soil = **C_{sn}**	mg/kg	Chemical-specific	Chemical-specific	Chemical-specific	Chemical-specific	Chemical-specific
Radionuclide chemical concentration in soil = **C_{sr}**	pCi/g	Chemical-specific	Chemical-specific	Chemical-specific	Chemical-specific	Chemical-specific
Exposure frequency = **EF**	day/year	350 (EPA 1989a)	250 (EPA 1991a)	40 (EPA 1992)	20	350 (EPA 1989a)
Exposure duration = **ED**	years	30 (EPA 1989a)	25 (EPA 1991a)	30 (EPA 1989a)	1	30 (EPA 1989a)
Conversion factor = **CF_5**	g/kg	1000	1000	1000	1000	1000
Volatilization factor = **VF**	m^3/kg	Chemical-specific	Chemical-specific	Chemical-specific	Chemical-specific	Chemical-specific
Fraction of vegetative cover = **V**	unitless	0.5 (EPA 1996)	0.5 (EPA 1996)	0.5 (EPA 1996)	0.5 (EPA 1996)	0.5 (EPA 1996)
Mean annual windspeed = **U_m**	m/s	4.69 (EPA 1996)	4.69 (EPA 1996)	4.69 (EPA 1996)	4.69 (EPA 1996)	4.69 (EPA 1996)
Equivalent threshold value of windspeed at 7 m = **U_t**	m/s	11.32 (EPA 1996)	11.32 (EPA 1996)	11.32 (EPA 1996)	11.32 (EPA 1996)	11.32 (EPA 1996)
Function dependent on **U_m/U_t= F(x)**	unitless	0.194 (Cowherd 1985)	0.194 (Cowherd 1985)	0.194 (Cowherd 1985)	0.194 (Cowherd 1985)	0.194 (Cowherd 1985)
Inverse of the mean concentration at the center of a 0.5 acre-square source = **Q/C**	(g m^3)/ (m^2 s kg)	90.8 (EPA 1996)	90.8 (EPA 1996)	90.8 (EPA 1996)	90.8 (EPA 1996)	90.8 (EPA 1996)
Seconds in an hour = **CF_3**	s/h	3600	3600	3600	3600	3600

Total inhalation rate = **IR_{air}**	m^3/day	20 (EPA 1989a)	20 (EPA 1989a)	6.7 (8 hours) (EPA 1992)	20 (EPA 1989a)	20 (EPA 1989a)
Conversion Factor = **CF_2**	days/yr	365	365	365	365	365
Body weight = **BW**	kg	70 (adult) (EPA 1991a)	70 (adult) (EPA 1991a)	70 (adult) (EPA 1991a)	70 (adult) (EPA 1991a)	70 (adult) (EPA 1991a)
Lifetime = **LT**	years	70 (EPA 1989a)	70 (EPA 1989a)	70 (EPA 1989a)	70 (EPA 1989a)	70 (EPA 1989a)
Averaging time = **AT**	years	LT (carcinogen) ED (noncarcinogen)	LT (carcinogen) ED (noncarcinogen)	LT (carcinogen) ED (noncarcinogen)	LT (carcinogen) ED (noncarcinogen)	LT (carcinogen) ED (noncarcinogen)

Soil/Sediment Dermal Contact

Equation 5 (non-radionuclides) and Table 4 present the exposure variables for the soil/sediment dermal contact pathway for the residential, industrial, and recreational scenarios.

$$Nonrad\ Intake_{der} = \frac{C_{sn}\, CF_4\, SA\, AF\, ABS\, EF\, ED}{CF_2\, BW\, AT} \quad (5)$$

Table 4. Soil/Sediment Dermal Contact Parameters

Parameter	Units	Residential	Industrial	Recreational	Agricultural
Non-radionuclide chemical concentration in soil = **C_{sn}**	mg/kg	Chemical-specific	Chemical-specific	Chemical-specific	Chemical-specific
Conversion factor = **CF_4**	(kg-cm^2)/ (mg-m^2)	0.01	0.01	0.01	0.01
Surface area = **SA**	m^2/day	0.53 Hand, forearms, head lower legs (EPA 1992)	0.316 Hands, forearms, head (EPA 1992)	0.53 Hand, forearms, head lower legs (EPA 1992)	0.53 Hand, forearms, head lower legs (EPA 1992)
Adherence factor = **AF**	mg/cm^2	1 (EPA 1992)	1 (EPA 1992)	1 (EPA 1992)	1 (EPA 1992)
Absorption factor = **ABS**	unitless	0.01 (organic) 0.001 (inorganic) (EPA 1995)	0.01 (organic) 0.001 (inorganic) (EPA 1995)	0.01 (organic) 0.001 (inorganic) (EPA 1995)	0.01 (organic) 0.001 (inorganic) (EPA 1995)

Exposure frequency = **EF**	day/yr	350 (EPA 1991)	250 (EPA 1991a)	40 (EPA 1992)	350 (EPA 1991)
Exposure duration = **ED**	years	30 (EPA 1989a)	25 (EPA 1991a)	30 (EPA 1989a)	30 (EPA 1989a)
Body weight = **BW**	kg	70 (adult) (EPA 1991a)	70 (adult) (EPA 1991a)	70 (adult) (EPA 1991a)	70 (adult) (EPA 1991a)
Conversion Factor = CF_2	days/yr	365	365	365	365
Lifetime = **LT**	years	70 (EPA 1989a)	70 (EPA 1989a)	70 (EPA 1989a)	70 (EPA 1989a)
Averaging time = **AT**	years	LT (carcinogen) ED (noncarcinogen)	LT (carcinogen) ED (noncarcinogen)	LT (carcinogen) ED (noncarcinogen)	LT (carcinogen) ED (noncarcinogen)

External Exposure

Equation 6 (radionuclides) and Table 5 present the exposure variables for the external exposure pathway for the residential, industrial, recreational, excavation, and recreational scenarios.

$$Rad\ Dose_{ext} = C_{sr}(1 - S_e)\,T_e\ ED\ EF\ CF_9 \qquad (6)$$

Table 5. Soil/Sediment External Exposure Parameters

Parameter	Units	Residential	Industrial	Recreational	Excavation	Agricultural
Radionuclide chemical concentration in soil = C_{sr}	pCi/g	Chemical-specific	Chemical-specific	Chemical-specific	Chemical-specific	Chemical-specific
Gamma Shielding Factor = S_e	unitless	0.2 (EPA 1991a)	0.2 (EPA 1991a)	0.2 (EPA 1991a)	0.2 (EPA 1991a)	0.2 (EPA 1991a)
Gamma exposure time factor = T_e	unitless	1 (EPA 1991a)	8/24 (EPA 1991a)	1/24 (EPA 1991a)	8/24 (EPA 1991a)	1 (EPA 1991a)
Exposure frequency = **EF**	days/yr	350 (EPA 1989a)	250 (EPA 1991a)	40 (EPA 1992)	20	350 (EPA 1989a)
Exposure duration = **ED**	years	24 (adult) 6 (child)	25 (adult) (EPA 1991a)	24 (adult) 6 (child)	1	24 (adult) 6 (child)

		(EPA 1989a)		(EPA 1989a)		(EPA 1989a)
Conversion factor = **CF_9**	yr/days	1/365	1/365	1/365	1/365	1/365

Soil/Sediment Produce Ingestion

Equation 7 (non-radionuclides), equation 8 (radionuclides), and Table 6 present the exposure variables for the soil/sediment produce ingestion pathway. The produce ingestion pathway is conducted for the agricultural scenario only.

$$Nonrad\ Intake_{pring} = \frac{C_{sn}(BV_{wet} + MLF)\,FI_v\,IR_v\,EF\,ED}{CF_2\,BW\,AT} \quad (7)$$

$$Rad\ Intake_{pring} = C_{sr}(BV_{wet} + MLF)\,CF_5\,FI_v\,IR_v\,EF\,ED \quad (8)$$

Table 6. Soil/Sediment Produce Ingestion Parameters

Parameter	Units	Agricultural
Non-radionuclide chemical concentration in soil = **C_{sn}**	mg/kg	Chemical-specific
Radionuclide chemical concentration in soil = **C_{sr}**	pCi/g	Chemical-specific
Soil to plant uptake factor (wet) = **BV_{wet}**	kg/kg	Chemical-specific
Mass loading factor = **MLF**	unitless	0.26 (Pinder and McLeod 1989)
Conversion factor = **CF_5**	g/kg	1000
Diet fraction = **FI_v**	unitless	0.4 (EPA 1989b)
Ingestion rate = **IR_v**	kg/d	0.2 (EPA 1989b)
Exposure frequency = **EF**	d/year	350 (EPA 1989a)
Exposure duration = **ED**	years	30 (EPA 1989a)
Conversion Factor = **CF_2**	days/yr	365

Body weight (adult) = **BW**	kg	70 (EPA 1989a)
Lifetime = **LT**	years	70 (EPA 1989a)
Averaging time = **AT**	years	LT (carcinogen) ED (noncarcinogen)

Soil/Sediment Beef Ingestion

Equation 9 (non-radionuclides), equation 10 (radionuclides), and Table 7 present the exposure variables for the soil/sediment beef ingestion pathway. The beef ingestion pathway is conducted for the agricultural scenario only.

$$Nonrad\ Intake_{beef\ ing} = \frac{F_f C_{sn} f_p (Q_p f_s (BV_{dry} + MLF) + Q_s) IR_f FI\ EF\ ED}{CF_2\ BW\ AT} \quad (9)$$

$$Rad\ Intake_{beef\ ing} = F_f C_{sr} f_p (Q_p f_s (BV_{dry} + MLF) + Q_s) CF_3 IR_f FI\ EF\ ED \quad (10)$$

Table 7. Soil/Sediment Beef Ingestion Parameters

Parameter	Units	Agricultural
Non-radionuclide chemical concentration in soil = C_{sn}	mg/kg	Chemical-specific
Radionuclide chemical concentration in soil = C_{sr}	pCi/g	Chemical-specific
Beef transfer coefficient = F_f	day/kg	Chemical-specific
Fraction of year animal is on site = f_p	unitless	1 (Site-specific)
Soil to plant uptake factor (dry) = BV_{dry}	kg/kg	Chemical-specific
Mass loading factor = **MLF**	unitless	0.26 (Pinder and McLeod 1989)
Quantity of pasture ingested = Q_p	kg/day	7.2 (IAEA 1994)

Quantity of soil ingested = **Q_s**	kg/day	1 (Darwin 1990)
Fraction of animal feed from site = **f_s**	unitless	1 (Site-specific)
Beef ingestion rate[c] = **IR_f**	kg/day	0.075 (EPA 1989b)
Conversion factor = **CF_5**	g/kg	1000
Diet fraction = **FI**	unitless	1 (Site-specific)
Exposure frequency = **EF**	day/yr	350 (EPA 1989a)
Exposure duration = **ED**	years	30 (EPA 1989a
Conversion Factor = **CF_2**	days/yr	365
Body weight = **BW**	kg	70 (EPA 1989a)
Lifetime = **LT**	years	70 (EPA 1989a)
Averaging time = **AT**	years	LT (carcinogen) ED (noncarcinogen)

Soil/Sediment Milk Ingestion

Equation 11 (non-radionuclides), equation 12 (radionuclides), and Table 8 present the exposure variables for the soil/sediment milk ingestion pathway. The milk ingestion pathway is conducted for the agricultural pathway only.

$$Nonrad\ Intake_{milking} = \frac{F_m C_{sn} f_p (Q_p f_s (BV_{dry} + MLF) + Q_s)\, IR_m\, FI\, EF\, ED}{CF_2\, BW\, AT} \quad (11)$$

$$Rad\ Intake_{milking} = F_m C_{sr} f_p (Q_p f_s (BV_{dry} + MLF) + Q_s)\, CF_5\, IR_m\, FI\, EF\, ED \quad (12)$$

Table 8. Soil/Sediment Milk Ingestion Parameters

Parameter	Units	Agricultural
Non-radionuclide chemical concentration in soil = $\mathbf{C_{sn}}$	mg/kg	Chemical-specific
Radionuclide chemical concentration in soil = $\mathbf{C_{sr}}$	pCi/g	Chemical-specific
Milk transfer coefficient = $\mathbf{F_m}$	day/L	Chemical-specific
Fraction of year animal is on site = $\mathbf{f_p}$	unitless	1 (Site-specific)
Soil to plant uptake factor (dry) = $\mathbf{BV_{dry}}$	kg/kg	Chemical-specific
Mass loading factor = **MLF**	unitless	0.26 (Pinder and McLeod 1989)
Quantity of pasture ingested = $\mathbf{Q_p}$	kg/day	16.1 (IAEA 1994)
Quantity of soil ingested = $\mathbf{Q_s}$	kg/day	1 (Darwin 1990)
Fraction of animal feed from site = $\mathbf{f_s}$	unitless	1 (Site-specific)
Conversion factor = $\mathbf{CF_5}$	g/kg	1000
Diet fraction = **FI**	unitless	1 (Site-specific)
Ingestion Rate = $\mathbf{IR_m}$	L/d	0.509 (adult) 0.305 (child) (EPA 1989b)
Exposure frequency = **EF**	d/year	350 (EPA 1989a)
Exposure duration = **ED**	years	24 (adult) 6 (child) (EPA 1989a)
Body weight = **BW**	kg	70 (adult) 15 (child)

		(EPA 1991a)
Lifetime = **LT**	years	70 (EPA 1989a)
Averaging time = **AT**	yr H day/yr	70 H 365 (carcinogen) ED H 365 (noncarcinogen)

SURFACE WATER/ GROUNDWATER EXPOSURE PATHWAYS

Exposure pathways evaluated for surface water and groundwater include ingestion, indoor inhalation, dermal contact, and agricultural pathways. Table 9 summarizes the pathways that can be evaluated for each scenario in SADA.

Table 9. Soil/Sediment Exposure Pathways by Scenario

Landuse/Pathway	Residential	Industrial	Recreational	Excavation	Agricultural
Incidental Ingestion	Yes	Yes	Yes	No	Yes
Inhalation	Yes	Yes	Yes	No	Yes
Dermal Contact	Yes	Yes	Yes	No	Yes
Vegetable Ingestion	Yes	No	No	No	Yes
Beef Ingestion	Yes	No	No	No	Yes
Milk Ingestion	Yes	No	No	No	Yes
Fish ingestion	Yes	No	Yes	No	Yes

Surface Water/Groundwater Ingestion

Equation 13 (non-radionuclides), equation 14 (radionuclides), and Table 10 present the exposure variables for the surface water/groundwater ingestion pathway. This pathway is conducted for the residential, industrial, and inhalation pathways.

$$Nonrad\ Intake_{ing} = \frac{C_{wn}\, IR_w\, EF\, ED}{CF_2\, BW\, AT} \quad (13)$$

$$Rad\ Intake_{ing} = C_{wr}\, IR_w\, EF\, ED \quad (14)$$

Table 10. Surface Water/Groundwater Ingestion Parameters

Parameter	Units	Residential	Industrial	Recreational	Agricultural
Non-radionuclide chemical concentration in water = C_{wn}	mg/L	Chemical-specific	Chemical-specific	Chemical-specific	Chemical-specific
Radionuclide chemical concentration in water = C_{wr}	pCi/L	Chemical-specific	Chemical-specific	Chemical-specific	Chemical-specific
Ingestion Rate = IR_w	L/d	2 (EPA 1989a)	1 (EPA 1991a)	.05 (EPA 1995)	2 (EPA 1989)
Exposure frequency = **EF**	d/year	350 (EPA 1989a)	250 (EPA 1991a)	40 (EPA 1992)	350 (EPA 1989a)
Exposure duration = **ED**	years	30 (EPA 1989a)	25 (EPA 1991a)	30 (EPA 1989a)	30 (EPA 1989a)
Body weight = **BW**	kg	70 (EPA 1989a)	70 (EPA 1989a)	70 (EPA 1989a)	70 (EPA 1989a)
Conversion Factor = CF_2	days/yr	365	365	365	365
Lifetime = **LT**	years	70 (EPA 1989a)	70 (EPA 1989a)	70 (EPA 1989a)	70 (EPA 1989a)
Averaging time = **AT**	years	LT (carcinogen) ED (noncarcinogen)	LT (carcinogen) ED (noncarcinogen)	LT (carcinogen) ED (noncarcinogen)	LT (carcinogen) ED (noncarcinogen)

Surface Water/Groundwater Indoor Inhalation

Equation 15 (non-radionuclides), equation 16 (radionuclides), and Table 11 present the exposure variables for the surface water/groundwater inhalation pathway from showering and from indoor water use. This pathway is conducted for the residential and agricultural scenarios only. The industrial and recreational default intake rates are set to 0 m^3/day.

$$Nonrad\ Intake_{ink} = \frac{C_{wn}\ VF\ IR_{air}\ EF\ ED}{CF_2\ BW\ AT} \quad (15)$$

$$Rad\ Intake_{ink} = C_{wr}\ IR_{air}\ CF_9\ IEF\ EF\ ED \quad (16)$$

Table 11. Surface Water/Groundwater Inhalation while Showering Parameters

Parameter	Units	Residential	Industrial	Recreational	Agricultural

Non-radionuclide chemical concentration in water = **C_{wn}**	mg/L	Chemical-specific	Chemical-specific	Chemical-specific	Chemical-specific
Radionuclide chemical concentration in water = **C_{wr}**	pCi/L	Chemical-specific	Chemical-specific	Chemical-specific	Chemical-specific
Volatilization Factor = **VF**	L/m^3	Chemical-specific	Chemical-specific	Chemical-specific	Chemical-specific
Inhalation rate = **IR_{air}**	m^3/hour	20 (EPA 1989a)	0	0	20 (EPA 1989a)
Exposure frequency = **EF**	day/year	350 (EPA 1991)	250 (EPA 1991a)	40 (EPA 1992)	350 (EPA 1991)
Exposure duration = **ED**	years	30 (EPA 1989a)	25 (EPA 1991a)	30 (EPA 1989a)	30 (EPA 1989a)
Inhalation exposure factor = **IEF**	(L hr)/ (m^3 day)	0.2802 (Tritium) 7.603 (Radon) 0 (other radionuclides)	0.2802 (Tritium) 7.603 (Radon) 0 (other radionuclides)	0.2802 (Tritium) 7.603 (Radon) 0 (other radionuclides)	0.2802 (Tritium) 7.603 (Radon) 0 (other radionuclides)
Body weight = **BW**	kg	70 (EPA 1989a)	70 (EPA 1989a)	70 (EPA 1989a)	70 (EPA 1989a)
Conversion Factor = **CF_9**	days/hr	1/24	1/24	1/24	1/24
Conversion Factor = **CF_2**	days/yr	365	365	365	365
Lifetime = **LT**	years	70 (EPA 1989a)	70 (EPA 1989a)	70 (EPA 1989a)	70 (EPA 1989a)
Averaging time = **AT**	years	LT (carcinogen) ED (noncarcinogen)	LT (carcinogen) ED (noncarcinogen)	LT (carcinogen) ED (noncarcinogen)	LT (carcinogen) ED (noncarcinogen)

Surface Water/Groundwater Dermal Contact

Equation 17 (non-radionuclides) and Table 12 present the exposure variables for the surface water/groundwater dermal contact pathway. This pathway is conducted for the residential, recreational, and agricultural scenarios only. The industrial scenario has the skin surface area exposed set to 0 m^3 and the exposure time is set to 0 hours.

$$Nonrad\ Intake_{der} = \frac{C_{wn}\, SA\, P_c\, CF_6\, ED\, EF\, ET}{CF_2\, BW\, AT} \quad (17)$$

Table 12. Surface Water/Groundwater Dermal Contact Parameters

Parameter	Units	Residential	Industrial	Recreational	Agricultural
Non-radionuclide chemical concentration in water = **C_{wn}**	mg/L	Chemical-specific	Chemical-specific	Chemical-specific	Chemical-specific
Radionuclide chemical concentration in water = **C_{wr}**	pCi/L	Chemical-specific	Chemical-specific	Chemical-specific	Chemical-specific
Skin surface area exposed[c] = **SA**	m^2	1.94 (EPA 1989a)	0	1.94 (EPA 1989a)	1.94 (EPA 1989a)
Skin permeability constant = **P_c**	cm/hr	Chemical-specific	Chemical-specific	Chemical-specific	Chemical-specific
Conversion Factor = **CF_6**	(L-m)/ ($cm\text{-}m^3$)	10	10	10	10
Exposure duration = **ED**	years	30 (EPA 1989a)	25 (EPA 1991a)	30 (EPA 1989a)	30 (EPA 1989a)
Exposure frequency = **EF**	events/yr	350 (EPA 1989a)	250 (EPA 1991a)	40 (EPA 1992)	350 (EPA 1989a)
Exposure time = **ET**	hrs/event	0.2 (EPA 1992)	0	2.6 (EPA 1989a)	0.2 (EPA 1992)
Body weight = **BW**	kg	70 (EPA 1989a)	70 (EPA 1989a)	70 (EPA 1989a)	70 (EPA 1989a)
Conversion Factor = **CF_2**	days/yr	365	365	365	365
Lifetime = **LT**	years	70 (EPA 1989a)	70 (EPA 1989a)	70 (EPA 1989a)	70 (EPA 1989a)
Averaging time = **AT**	years	LT (carcinogen) ED (noncarcinogen)	LT (carcinogen) ED (noncarcinogen)	LT (carcinogen) ED (noncarcinogen)	LT (carcinogen) ED (noncarcinogen)

Surface Water/Groundwater Produce Ingestion

Equation 18 (non-radionuclides), equation 19 (radionuclides), and Table 13 present the exposure variables for the surface water/groundwater produce ingestion pathway. The produce ingestion pathway is conducted for the agricultural pathway only.

$$Nonrad\ Intake_{proing} = \frac{C_{wn}\, r_{irr}\, f_{irr}\left[\frac{(BV_{wet} + MLF)(1 - \exp(-\lambda_1 t_b))}{P\ \lambda_1} + \frac{I_f\, T\,(1 - \exp(-\lambda_E t_v)}{Y_v\ \lambda_E}\right] FI_v\, IR_v\, EF\, ED}{CF_2\, BW\, AT}$$

(18)

$$Rad\ Intake_{proing} = C_{wr}\, r_{irr}\, f_{irr}\left[\frac{(BV_{wet} + MLF)(1 - \exp(-\lambda_1 t_b))}{P\ \lambda_1} + \frac{I_f\, T\,(1 - \exp(-\lambda_E t_v)}{Y_v\ \lambda_E}\right] FI_v\, IR_v\, EF\, ED$$

(19)

Table 13. Surface Water/Groundwater Produce Ingestion Parameters

Parameter	Units	Agricultural
Non-radionuclide chemical concentration in water = C_{wn}	mg/L	Chemical-specific
Radionuclide chemical concentration in water = C_{wr}	pCi/L	Chemical-specific
Irrigation rate = r_{irr}	L/m^2 day	2.08 (Kennedy and Strenge 1992)
Irrigation period = f_{irr}	unitless	0.25 (3 months)
Soil to plant uptake factor (wet) = BV_{wet}	kg/kg	Chemical-specific
Mass loading factor = **MLF**	unitless	0.26 (Pinder and McLeod 1989)
Effective removal rate = λ_r	1/day	$\lambda_l+\lambda_{hl}$
Soil leaching rate = λ_l	1/day	2.7E-5 (NCRP 1989)
Radionuclide half-life = λ_{hl}	1/day	Chemical-specific
Long-term deposition and buildup = t_b	day	10950 (NCRP 1985)
Areal density for root zone = **P**	kg/m^2	240 (Hoffman et al. 1982)
Interception fraction = I_f	unitless	0.42

		(Miller 1980)
Translocation factor = **T**	unitless	1 (McKone 1994)
Decay for removal on produce = λ_E	1/day	$\lambda_I+0.693/t_w$ (NCRP 1989)
Weathering half-life = t_w	1/day	14 (NCRP 1985)
Above ground exposure time = t_v	days	60 (NCRP 1985)
Plant yield (wet) = Y_v	kg/m^2	2 (NCRP 1985)
Diet fraction = FI_v	unitless	0.4 (EPA 1989b)
Ingestion rate = IR_v	kg/d	0.2 (EPA 1989b)
Exposure frequency = **EF**	d/year	350 (EPA 1989a)
Exposure duration = **ED**	years	30 (EPA 1989a)
Body weight (adult) = **BW**	kg	70 (EPA 1989a)
Conversion Factor = CF_2	days/yr	365
Lifetime = **LT**	years	70 (EPA 1989a)
Averaging time = **AT**	years	LT (carcinogen) ED (noncarcinogen)

Surface Water/Groundwater Beef Ingestion

Equation 20 (non-radionuclides), equation 21 (radionuclides), and Table 14 present the exposure variables for the surface water/groundwater beef ingestion pathway. The beef ingestion pathway is conducted for the agricultural pathway only.

$$Nonrad\ Intake_{beef\ ing} = \frac{C_{wn}\, Q_w\, Bf\ \ IR\ FI\ EF\ ED}{CF_2\, BW\ \ AT} \quad (20)$$

$$Rad\ \ Intake_{beef\ ing} = C_{wr}\, Q_w\, Bf\ \ IR\ FI\ EF\ ED \quad (21)$$

Table 14. Surface Water/ Groundwater Beef Ingestion Parameters

Parameter	Units	Agricultural
Non-radionuclide chemical concentration in water = **C_{wn}**	mg/L	Chemical-specific
Radionuclide chemical concentration in water = **C_{wr}**	pCi/L	Chemical-specific
Quantity of water ingested (cattle) = **Q_w**	L/day	50 (IAEA 1994)
Beef transfer coefficient = **Bf**	day/kg	Chemical-specific
Ingestion rate[c] = **IR**	kg/day	0.075 (EPA 1989b)
Conversion factor = **CF**	g/kg	1000
Diet fraction = **FI**	unitless	1
Exposure frequency = **EF**	day/yr	350 (EPA 1989a)
Exposure duration = **ED**	years	30 (EPA 1989a)
Body weight = **BW**	kg	70 (EPA 1989a)
Conversion Factor = **CF_2**	days/yr	365
Lifetime = **LT**	years	70 (EPA 1989a)
Averaging time = **AT**	years	LT (carcinogen) ED (noncarcinogen)

Surface Water/Groundwater Milk Ingestion

Equation 22 (non-radionuclides), equation 23 (radionuclides), and Table 15 present the exposure variables for the surface water/groundwater milk ingestion pathway. The milk ingestion pathway is conducted for the agricultural pathway only.

$$Nonrad\ Intake_{milking} = \frac{C_{wn}\ Bm\ Q_w\ IR_m\ FI\ EF\ ED}{CF_2\ BW\ AT} \quad (22)$$

$$Rad\ Intake_{milking} = C_{wr}\ Bm\ Q_w\ IR_m\ FI\ EF\ ED \quad (23)$$

Table 15. Surface Water/Groundwater Milk Ingestion Parameters

Parameter	Units	Agricultural
Non-radionuclide chemical concentration in water = **C_{wn}**	mg/L	Chemical-specific
Radionuclide chemical concentration in water = **C_{wr}**	pCi/L	Chemical-specific
Quantity of water ingested (dairy) = **Q_w**	L/day	75 (IAEA 1994)
Milk transfer coefficient = **Bm**	day/L	Chemical-specific
Ingestion Rate = **IR_m**	L/d	0.305 (adult) (EPA 1989b) 0.509 (child) (Pao et al. 1982)
Exposure frequency = **EF**	d/year	350 (EPA 1989a)
Exposure duration = **ED**	years	24 (adult) 6 (child) (EPA 1989a)
Body weight = **BW**	kg	70 (adult) 15 (child) (EPA 1991a)
Conversion Factor = **CF_2**	days/yr	365
Lifetime = **LT**	years	70 (EPA 1989a)

Averaging time = **AT**	years	LT (carcinogen) ED (noncarcinogen)

Surface Water Fish Ingestion

Equation 24 (non-radionuclides), equation 25 (radionuclides), and Table 16 present the exposure variables for the surface water fish ingestion pathway. The fish ingestion pathway is conducted for the recreational pathway only.

$$Nonrad\ Intake_{fisking} = \frac{C_{wn}\, B_{fish}\, IR_{fish}\, FI\, EF\, ED}{CF_2\, BW\, AT} \tag{24}$$

$$Rad\ Intake_{fisking} = C_{wr}\, B_{fish}\, IR_{fish}\, FI\, EF\, ED \tag{25}$$

Table 16. Surface Water Fish Ingestion Parameters

Parameter	Units	Agricultural
Non-radionuclide chemical concentration in water = **C_{wn}**	mg/L	Chemical-specific
Radionuclide chemical concentration in water = **C_{wr}**	pCi/L	Chemical-specific
Fish transfer coefficient = **B_{fish}**	day/L	Chemical-specific
Ingestion Rate = **IR_m**	kg/fish meal	0.054 (adult) (EPA 1991a)
Exposure frequency = **EF**	fish meal /year	45 (EPA 1995)
Exposure duration = **ED**	years	30 (EPA 1989a)
Body weight = **BW**	kg	70 (adult) (EPA 1991a)
Conversion Factor = **CF_2**	days/yr	365
Lifetime = **LT**	years	70 (EPA 1989a)
Averaging time = **AT**	years	LT (carcinogen) ED (noncarcinogen)

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