Handbook of Parameters for U.S. and International Governments Risk and Dose Assessment Models for Remediation of Radiologically Contaminated Soil

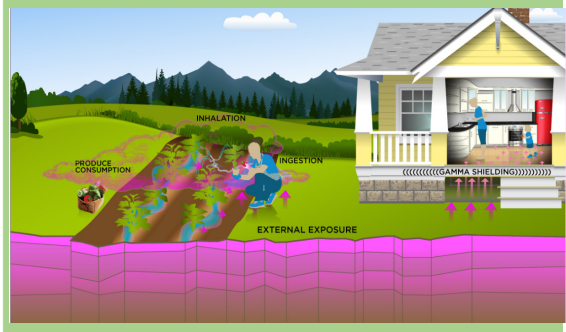
(PRG/DCC, RESRAD, NORMALYSA, RCLEA, RSRARS, WISMUT and NCRP)

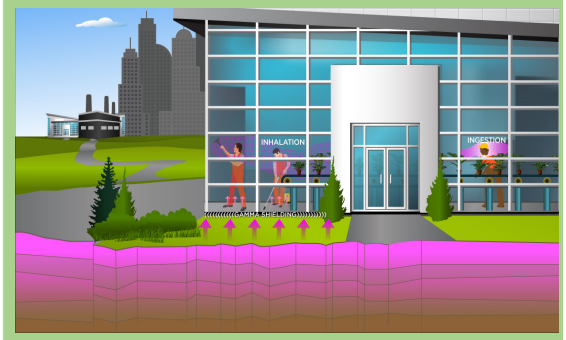
By

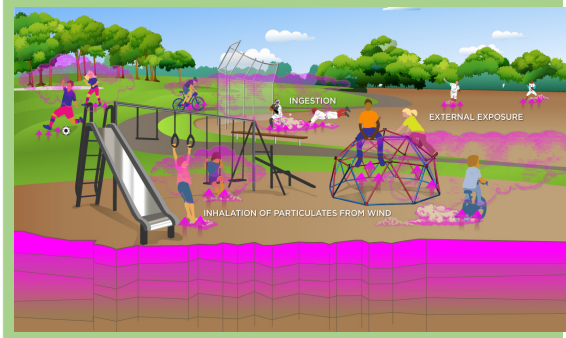
Nasser Shubayr, PhD

U.S. EPA Research Fellow, ORISE

October, 2017







ACKNOWLEDGMENTS

This project was supported in part by an appointment to the Research Participation Program at the Office of Superfund Remediation and Technology Innovation, U.S. Environmental Protection Agency (EPA), administered by the Oak Ridge Institute for Science and Education (ORISE) through an interagency agreement between the U.S. Department of Energy and EPA. This project was under the supervision of Mr. Stuart Walker of the EPA.

Contents

I. Introduction

Radiation risk assessment models are important tools for decision makers that are used to assess risk and dose for the public and workers due to radioactivity resulting from radioactively contaminated sites. These models can be used for remediation, decommissioning, decontamination etc. Models constructed in different ways as shown in Figure 1. Modeling and monitoring are necessary to comply with regulations as well as to determine the need for remediation in case a contaminated site constitutes a danger for people or the environment. The radiation risk assessment models are usually used to analyze the exposure sources and scenarios in order to produce guidelines for remediation and clean up actions. Generic assessment requires minimal information about the contaminated site and the default input parameters maybe used. Advanced assessment requires site-specific data for the relevant scenarios and pathways. Radiation risk assessment models have input parameters for relevant exposure scenarios and pathways that can be used for the assessment. This document shows a brief overview for the following models: PRG/DCC, RESRAD, NORMALYSA, RCLEA, RaSoRs, WISMUT and NCRP, and lists all input parameters used by these models. This document can be used as a parameters reference for modelers.

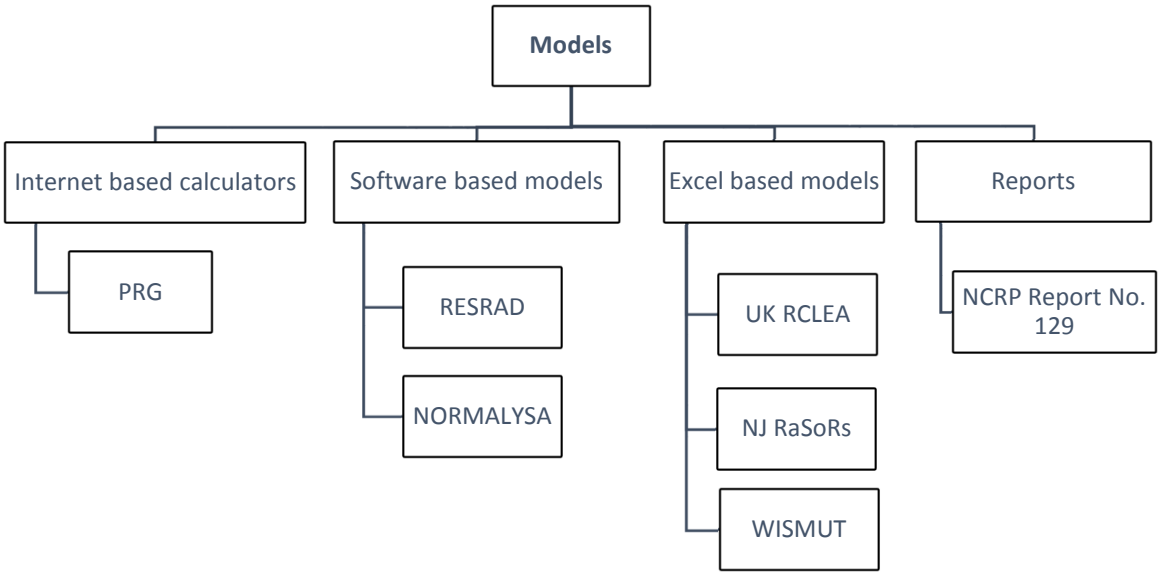


Figure 1: Models categories.

II. Preliminary Remediation Goal (PRG)

Preliminary Remediation Goals for Radionuclide Contaminants at Superfund Sites (PRG) is an electronic calculator developed by the U.S. Environmental Protection Agency (EPA). The PRG calculator presents risk-based standardized exposure parameters and equations that should be used for calculating radionuclide PRGs for residential, commercial/industrial, and agricultural land use exposures from soil, tap water, air and biota. Calculated PRGs can be produced generically (considered to be protective for humans, including the most sensitive groups) or using site-specific data for 1255 radionuclides in the PRG calculator which may be found at: https://epa-prgs.ornl.gov/radionuclides/. The PRG calculator was first issued in 2002 and last updated in 2017.

2.1 PRG Exposure Scenarios and Pathways

Scenario/ Land use	Media
Resident	Soil, air, 2-D external exposure, tap water, and fish
Composite worker	Soil, air, 2-D external exposure
Outdoor worker	Soil, air, 2-D external exposure
Indoor worker	Soil, air, 2-D external exposure
Construction worker—standard unpaved road vehicle traffic (site-specific only)	Soil, air, 2-D external exposure
Construction worker—wind erosion and other construction activities (site-specific only)	Soil, air, 2-D external exposure
Recreator (site-specific only)	Soil, air, 2-D external exposure, surface water, game and fowl
Farmer	Air, biota direct, combined soil and biota, combined water and biota, biota from both soil and water
Soil to groundwater	Soil
Cover Layer	May be added to soil or 2D for shielding from external exposure

Dose Compliance Concentration for Radionuclides at Superfund Sites (DCC) is also an electronic calculator developed by the U.S. EPA to address Applicable or Relevant and Appropriate Requirements (ARARs) that are expressed in terms of millirem per year. The DCC calculator equations are nearly identical to those in the PRG for Radionuclides. There are three key differences between the two tools: 1) the target dose rate (ARAR-based) is substituted for the target cancer risk (1×10^{-6}), 2) the period of exposure is one year, to indicate year of peak dose, and 3) dose conversion factor (DCF) is used in place of the slope factor. The DCC calculator may be found at the EPA website: https://epa-dccs.ornl.gov/. The DCC calculator was first issued in 2004 and last updated in 2017.

2.2 DCC Exposure Scenarios and Pathways

Scenario/ Land use	Media
Resident	Soil, air, 2-D external exposure, tap water, and fish
Composite worker	Soil, air, 2-D external exposure
Outdoor worker	Soil, air, 2-D external exposure
Indoor worker	Soil, air, 2-D external exposure
Construction worker—standard unpaved road vehicle traffic (site-specific only)	Soil, air, 2-D external exposure
Construction worker—wind erosion and other construction activities (site-specific only)	Soil, air, 2-D external exposure
Recreator (site-specific only)	Soil, air, 2-D external exposure, surface water, game and fowl
Farmer	Air, biota direct, combined soil and biota, combined water and biota, biota from both soil and water
Soil to groundwater **Cover Layer**	Soil May be added to soil/ 2D for shielding from radiation in an external exposure scenario.

2.3 PRG/DCC Recommended Default Input Parameters

Slope Factors

Slope factors provide cancer risk posed by lifetime exposure to specific radionuclides. Slope factors also take into account the type of exposure (inhalation, ingestion, or external) and amount of exposure. For example, a resident on a site would expect to have a different exposure level than a worker on the same site. PRG calculator uses slope factors to calculate cleanup levels based on a default target cancer risk of 10-6.

Parameter (units)	Default	Information/Reference
Slope Factor - external exposure (risk/yr per pCi/g)	RN-specific	ORNL 2014c
Slope Factor - external exposure (risk/yr per pCi/g)	RN-specific	ORNL 2014c
Slope Factor - external exposure (risk/yr per pCi/g)	RN-specific	ORNL 2014c
Slope Factor - external exposure (risk/yr per pCi/cm^2)	RN-specific	ORNL 2014c
Slope Factor - external exposure (risk/yr per pCi/g)	RN-specific	ORNL 2014c
Food Ingestion Slope Factor (risk/pCi)	RN-specific	ORNL 2014c
Slope Factor - inhalation (risk/pCi)	RN-specific	ORNL 2014c
Slope Factor - immersion (risk/yr per pCi/L)	RN-specific	ORNL 2014c
Soil Ingestion Slope Factor - population (risk/pCi)	RN-specific	ORNL 2014c
Soil Ingestion Slope Factor - adult only (risk/pCi)	RN-specific	ORNL 2014c
Slope Factor - submersion (risk/yr per pCi/cm^3): For use in this tool, ORNL 2014c units were converted to (risk/yr per pCi/m^3)	RN-specific	ORNL 2014c
Water Ingestion Slope Factor (risk/pCi)	RN-specific	ORNL 2014c

Dose and Decay Constant Variables

Parameter (units)	Default	Information/Reference
Time - construction worker (years)	1	U.S. EPA 2002 Exhibit 5-1
Time - farmer (years)	40	U.S. EPA 2005 (pg. C-24/C-26)
Time - indoor worker (years)	25	U.S. EPA 1991a (pg. 15)
Time - outdoor worker (years)	25	U.S. EPA 1991a (pg. 15)
Target Risk	1×10^{-6}	U.S. EPA 1991b Target cancer risk of 10-6 means that a person exposed to the contamination has a one in a million chance of developing cancer. (Target is based on upper bound estimated level of reasonable maximum exposure (RME). Most people will have less of a chance of developing cancer)
Time - recreator (years)	site-specific	site-specific
Time - resident (years)	26	U.S. EPA 2011a, Table 16-108; 90th percentile or current residence time.
Time - worker (years)	25	U.S. EPA 1991a (pg. 15)
decay constant = 0.693/half-life ($year^{-1}$) where 0.693 = ln(2)	RN-specific	Developed for Radionuclide Soil Screening calculator

Miscellaneous Variables

Parameter (units)	Default	Information/Reference
Area Correction Factor - 15cm (unitless)	RN-specific	The area correction factor is the ratio of a dose rate coefficient from a finite contaminated slab to a dose rate coefficient from an infinite source. ORNL 2014a
Area Correction Factor - 1cm (unitless)	RN-specific	ORNL 2014a
Area Correction Factor - 5cm (unitless)	RN-specific	ORNL 2014a
Area Correction Factor - ground plane (unitless)	RN-specific	ORNL 2014a
Area Correction Factor - soil volume (unitless)	RN-specific	ORNL 2014a
Beef Contaminated Fraction - farmer (unitless)	1	Developed for Radionuclide Soil Screening calculator
Dairy Contaminated Fraction - farmer (unitless)	1	Developed for Radionuclide Soil Screening calculator
Egg Contaminated Fraction - Farmer (unitless)	1	Developed for Radionuclide Soil Screening calculator
Fish Contaminated Fraction - farmer (unitless)	1	Developed for Radionuclide Soil Screening calculator
Goat Contaminated Fraction - Farmer (unitless)	1	Developed for Radionuclide Soil Screening calculator
Goat Milk Contaminated Fraction - Farmer (unitless)	1	Developed for Radionuclide Soil Screening calculator
Poultry Contaminated Fraction - farmer (unitless)	1	Developed for Radionuclide Soil Screening calculator
Produce Contaminated Fraction - farmer (unitless)	1	U.S. EPA 2011, U.S. EPA 2005
Sheep Contaminated Fraction - Farmer (unitless)	1	Developed for Radionuclide Soil Screening calculator
Sheep Milk Contaminated Fraction - Farmer (unitless)	1	Developed for Radionuclide Soil Screening calculator
Swine Contaminated Fraction - farmer (unitless)	1	Developed for Radionuclide Soil Screening calculator
Produce Contaminated Fraction - resident (unitless)	1	U.S. EPA 2011, U.S. EPA 2005
Gamma Shielding Factor - Air (unitless)	1	Developed for Radionuclide Soil Screening calculator
Gamma Shielding Factor - building (unitless)	$GSF_i \times GSF_o$	Developed for Radionuclide Soil Screening calculator
Gamma Shielding Factor - Indoor (unitless)	0.4	U.S. EPA 2000a. (pg. 2-22). U.S. EPA 2000b. (pg. 2-18)
Gamma Shielding Factor - 15cm (unitless)	RN-specific	ORNL 2014b
Gamma Shielding Factor - 1cm (unitless)	RN-specific	ORNL 2014b
Gamma Shielding Factor - 5cm (unitless)	RN-specific	ORNL 2014b
Gamma Shielding Factor - ground plane (unitless)	RN-specific	ORNL 2014b

(cont.) Miscellaneous Variables		
Parameter (units)	**Default**	**Information/Reference**
Gamma Shielding Factor - soil volume (unitless)	RN-specific	ORNL 2014a
Andelman Volatilization Factor (L/m^3)	0.5	U.S. EPA 1991b (pg. 20), Based primarily on experimental data on the volatilization of radon from household uses of water, Andelman (1990) derived an equation that defines the relationship between the concentration of a contaminant in household water and the average concentration of the volatilized contaminant in air.
Density of milk (kg/L)	1.03	Milk Composition & Synthesis Resource Library

Tissue Transfer Factors and Animal Ingestion Rates of Fodder, Water, and Soil

Parameter (units)	Default	Information/Reference
Fish Transfer Factor (L/kg)	RN-specific	hierarchy selection in ORNL (2016)
Soil to Plant Transfer Factor - dry (pCi/g-dry plant per pCi/g-dry soil)	RN-specific	hierarchy selection in ORNL (2016)
Soil to Plant Transfer Factor - wet (pCi/g-fresh plant per pCi/g-dry soil)	RN-specific	hierarchy selection in ORNL (2016)
Irrigation Period (unitless)	0.25	Personal communication
Animal On-site Fraction - beef (unitless)	1	Developed for this calculator
Animal On-site Fraction - dairy (unitless)	1	Developed for this calculator
Animal On-site Fraction - goat (unitless)	1	Developed for this calculator
Animal On-site Fraction - goat milk (unitless)	1	Developed for this calculator
Animal On-site Fraction - poultry (unitless)	1	Developed for this calculator
Animal On-site Fraction - sheep (unitless)	1	Developed for this calculator
Animal On-site Fraction - sheep milk (unitless)	1	Developed for this calculator
Animal On-site Fraction - swine (unitless)	1	Developed for this calculator
Fraction of Year Animal On Site - beef (unitless)	1	Developed for this calculator
Fraction of Year Animal On Site - dairy (unitless)	1	Developed for this calculator
Fraction of Year Animal On Site - goat (unitless)	1	Developed for this calculator
Fraction of Year Animal On Site - goat milk (unitless)	1	Developed for this calculator
Fraction of Year Animal On Site - poultry (unitless)	1	Developed for this calculator
Fraction of Year Animal On Site - sheep (unitless)	1	Developed for this calculator
Fraction of Year Animal On Site - sheep milk (unitless)	1	Developed for this calculator
Fraction of Year Animal On Site - swine (unitless)	1	Developed for this calculator
Interception Fraction (unitless)	0.42	Miller, C. W. 1980, The fraction of deposited materials intercepted and initially retained (i.e. not immediately blown or washed off) by vegetation.
Irrigation Rate (L/m^2)	3.62	Personal communication
aerial deposition from irrigation multiplier	RN-specific	Calculated
resuspension from irrigation multiplier	RN-specific	Calculated
root uptake from irrigation multiplier	RN-specific	Calculated

(cont.) Tissue Transfer Factors and Animal Ingestion Rates of Fodder, Water, and Soil

Parameter (units)	Default	Information/Reference
Pasture Plant Mass Loading Factor (g dry soil per g dry plant)	0.25	Hinton, T. G. 1992
Produce Plant Mass Loading Factor (g dry soil per g fresh plant)	plant-specific	ORNL (2016)
Area Density for Root Zone (kg/m^2)	240	Hoffman, F. O., R. H. Gardner, and K. F. Eckerman. 1982; Peterson, H. T., Jr. 1983; McKone, T. E. 1994
Beef Fodder Intake Rate (kg/day)	11.77	U.S. EPA 2005 (pg. B-138)
Dairy Fodder Intake Rate (kg/day)	20.3	U.S. EPA 2005 (pg. B-145)
Goat Fodder Intake Rate (kg/day)	1.27	Lyons et. al. 1999
Goat Milk Fodder Intake Rate (kg/day)	1.59	Lyons et. al. 1999 and Tarr
Chicken Fodder Intake Rate (kg/day) Duck Fodder Intake Rate (kg/day) Turkey Fodder Intake Rate (kg/day) Goose Fodder Intake Rate (kg/day)	0.2 0.24 0.68 0.33	U.S. EPA 2005 (pg. B-158/164) NRC 1994 NRC 1994 NRC 1994
Sheep Fodder Intake Rate (kg/day)	1.75	Lyons et. al. 1999 and OMAFRA
Sheep Milk Fodder Intake Rate (kg/day)	3.15	Lyons et. al. 1999 and OMAFRA
Swine Fodder Intake Rate (kg/day)	4.7	U.S. EPA 2005 (pg. B-152)
Beef Soil Intake Rate (kg/day)	0.5	U.S. EPA 2005 (pg. B-139)
Dairy Soil Intake Rate (kg/day)	0.4	U.S. EPA 2005 (pg. B-146)
Goat Soil Intake Rate (kg/day)	0.23	Handbook of Ecotoxicology (Q_s is 18% of Q_p: sheep surrogate used)
Goat Milk Soil Intake Rate (kg/day)	0.29	Handbook of Ecotoxicology (Q_s is 18% of Q_p: sheep surrogate used)
Chicken Soil Intake Rate (kg/day) Duck Soil Intake Rate (kg/day) Turkey Soil Intake Rate (kg/day) Goose Soil Intake Rate (kg/day)	0.022 0.024 0.068 0.033	U.S. EPA 2005 (pg. B-159/165) NRC 1994 (Q_s is 10% of Q_p) NRC 1994 (Q_s is 10% of Q_p) NRC 1994 (Q_s is 10% of Q_p)
Sheep Soil Intake Rate (kg/day)	0.32	Handbook of Ecotoxicology (Q_s is 18% of Q_p)
Sheep Milk Soil Intake Rate (kg/day)	0.57	Handbook of Ecotoxicology (Q_s is 18% of Q_p)
Swine Soil Intake Rate (kg/day)	0.37	U.S. EPA 2005 (pg. B-153)
Beef Water Intake Rate (L/day)	53	U.S. EPA 1999a (pg 10-23). U.S. EPA 1997b.
Dairy Water Intake Rate (L/day)	92	U.S. EPA 1999a (pg 10-23). U.S. EPA 1997b.
Goat Water Intake Rate (L/day)	3.81	Tarr
Goat Milk Water Intake Rate (L/day)	8.75	Tarr

(cont.) Tissue Transfer Factors and Animal Ingestion Rates of Fodder, Water, and Soil

Parameter (units)	Default	Information/Reference
Chicken Water Intake Rate (L/day) Duck Water Intake Rate (L/day) Turkey Water Intake Rate (L/day) Goose Water Intake Rate (L/day)	0.4 0.48 1.36 0.66	U.S. EPA 2005 (pg. B-159/165), NRC 1994 pg.15 ($Q_w=2\times Q_p$)
Sheep Water Intake Rate (L/day)	5.25	OMAFRA
Sheep Milk Water Intake Rate (L/day)	10.4	OMAFRA
Swine Water Intake Rate (L/day)	11.4	NEC, Swine Nutrition Guide (pg. 19). U.S. EPA 1998 (pg B-180)
soil resuspension multiplier (g dry soil per g fresh plant)	=MLF (pasture or produce)	Hinton 1992
dry root uptake for pasture multiplier (pCi/g-dry plant per pCi/g-dry soil)	RN-specific ($=Bv_{dry}$)	hierarchy selection in ORNL (2016)
wet root uptake for produce multiplier (pCi/g-fresh plant per pCi/g-dry soil)	RN-specific ($=Bv_{wet}$)	hierarchy selection in ORNL (2016)
Translocation Factor (unitless)	1	NCRP 1984
Long Term Deposition and Buildup (day)	10950	NCRP 1985
Beef Transfer Factor (day/kg)	RN-specific	hierarchy selection in ORNL (2016)
Dairy Transfer Factor (day/L)	RN-specific	hierarchy selection in ORNL (2016)
Egg Transfer Factor (day/kg)	RN-specific	hierarchy selection in ORNL (2016)
Goat Transfer Factor (day/kg)	RN-specific	hierarchy selection in ORNL (2016)
Goat Milk Transfer Factor (day/L)	RN-specific	hierarchy selection in ORNL (2016)
Poultry Transfer Factor (day/kg)	RN-specific	hierarchy selection in ORNL (2016)
Sheep Transfer Factor (day/kg)	RN-specific	hierarchy selection in ORNL (2016)
Sheep Milk Transfer Factor (day/L)	RN-specific	hierarchy selection in ORNL (2016)
Swine Transfer Factor (day/kg)	RN-specific	hierarchy selection in ORNL (2016)
Above Ground Exposure Time (day)	60	NCRP 1985
Weathering Half-life (day)	14	NCRP 1989
Plant Yield - wet (kg/m^2)	2	NCRP 1985
Effective Rate of Removal from Soil (1/day)	$\lambda_{HL} + \lambda_i$	NCRP 1989
Effective Rate of Removal from Produce (1/day)	$\lambda_i + (0.693/t_w)$	NCRP 1989
Rate of removal from soil by harvesting or leaching (1/day)	0.000027	NCRP 1989
decay of parent or daughter products (1/day)	0.693/HL(days)	NCRP 1989

Inhalation, Ingestion, and Consumption Rates

Parameter (units)	Default	Information/Reference
Recreator Immersion Factor - age-adjusted (hours)	site-specific	U.S. EPA 1991a (pg. 15)
Farmer Inhalation Fraction - age-adjusted (m^3)	259,000	Calculated using the age-adjusted intake factors equation. This fraction is to take into account the different between children and adults, age adjusted fractions are used to account for changes in the receptor ages.
Recreator Inhalation Fraction - age-adjusted (m^3)	site-specific	Calculated using the age-adjusted intake factors equation.
Resident Inhalation Rate - age-adjusted (m^3)	161,100	Calculated using the age-adjusted intake factors equation.
Farmer Beef Ingestion Fraction - age-adjusted (g)	2,098,950	Calculated using the aged adjusted intake factors equation
Farmer Dairy Ingestion Fraction - age-adjusted (g)	10,138,030	Calculated using the aged adjusted intake factors equation
Farmer Egg Ingestion Rate - age-adjusted (g)	775,810	Calculated using the aged adjusted intake factors equation
Farmer Produce Ingestion Fraction - age-adjusted (g)	plant-specific	Calculated using the aged adjusted intake factors equation
Farmer Fish Ingestion Fraction - age-adjusted (g)	10,018,960	Calculated using the aged adjusted intake factors equation
Farmer Poultry Ingestion Fraction - age-adjusted (g)	1,376,550	Calculated using the aged adjusted intake factors equation
Resident Produce Ingestion Fraction - age-adjusted (g)	plant-specific	Calculated using the aged adjusted intake factors equation
Farmer Soil Ingestion Fraction - age-adjusted (mg)	1,610,000	Calculated using the age-adjusted intake factors equation.
Recreator Ingestion Fraction - age-adjusted (mg)	site-specific	Calculated using the age-adjusted intake factors equation.
Resident Ingestion Fraction - age-adjusted (mg)	1,120,000	Calculated using the age-adjusted intake factors equation.
Farmer Swine Ingestion Fraction - age-adjusted (g)	1,171,520	Calculated using the aged adjusted intake factors equation
Recreator Surface Water Ingestion Fraction - age-adjusted (L)	site-specific	Calculated using the age-adjusted intake factors equation.
Resident Tapwater Ingestion Rate - age-adjusted (L)	19,138	Calculated using the age-adjusted intake factors equation.
Construction Worker Inhalation Rate (m^3/day; based on a rate of 2.5m^3/hour for 24 hours)	60	U.S. EPA 1997a (pg. 5-11)
Soil Inhalation Rate - adult farmer(m^3/day)	20	U.S. EPA 1991a (pg. 15)
Farmer Inhalation Rate - child (m^3/day)	10	U.S. EPA 1997a (pg. 5-11)
Indoor Worker Inhalation Rate (m^3; based on a rate of 2.5m^3/hour for 24 hours)	60	U.S. EPA 1997a (pg. 5-11)
Outdoor Worker Inhalation Rate (m^3/day; based on a rate of 2.5m^3/hour for 24 hours)	60	U.S. EPA 1997a (pg. 5-11)
Recreator Inhalation Rate - adult (m^3/day)	20	U.S. EPA 1991a (pg. 15)

(cont.) Inhalation, Ingestion, and Consumption Rates

Parameter (units)	Default	Information/Reference
Recreator Inhalation Rate - child (m^3/day)	10	U.S. EPA 1997a (pg. 5-11)
Resident Inhalation Rate - adult (m^3/day)	20	U.S. EPA 1991a (pg. 15)
Resident Inhalation Rate - child (m^3/day)	10	U.S. EPA 1997a (pg. 5-11)
Composite Worker Inhalation Rate (m^3/day; based on a rate of 2.5m^3/hour for 24 hours)	60	U.S. EPA 1997a (pg. 5-11)
Farmer Beef Ingestion Rate - adult (g/day)	165.3	U.S. EPA 2011 (Table 13-33)
Farmer Beef Ingestion Rate - child (g/day)	62.8	U.S. EPA 2011 (Table 13-33)
Farmer Dairy Ingestion Rate - adult (g/day)	676.4	U.S. EPA 2011 (Table 11-4)
Farmer Dairy Ingestion Rate - child (g/day)	994.7	U.S. EPA 2011 (Table 11-4)
Farmer Egg Ingestion Rate - adult (g/day)	59.6	U.S. EPA 2011 (Table 13-40)
Farmer Egg Ingestion Rate - child (g/day)	31.7	U.S. EPA 2011 (Table 13-40)
Farmer Produce Ingestion Rate - adult (g/day)	plant-specific	U.S. EPA 2011 (Table 13-10)
Farmer Produce Ingestion Rate - child (g/day)	plant-specific	U.S. EPA 2011 (Table 13-10)
Farmer Fish Ingestion Rate - adult (g/day)	831.8	U.S. EPA 2011 (Table 13-20)
Farmer Fish Ingestion Rate - child (g/day)	57.4	U.S. EPA 2011 (Table 13-20)
Resident Fish Ingestion Rate (g/day)	54	U.S. EPA 1991a (page 15)
Farmer Poultry Ingestion Rate - adult (g/day)	107.4	U.S. EPA 2011 (Table 13-52)
Farmer Poultry Ingestion Rate - child (g/day)	46.9	U.S. EPA 2011 (Table 13-52)
Resident Produce Ingestion Rate - adult (g/day)	plant-specific	U.S. EPA 2011 (Table 13-10)
Resident Produce Ingestion Rate - child (g/day)	plant-specific	U.S. EPA 2011 (Table 13-10)
Construction Worker Soil Ingestion Rate (mg/day)	330	
Farmer Soil Ingestion Rate - adult (mg/day)	100	U.S. EPA 1991a (pg. 15)
Farmer Soil Ingestion Rate - child (mg/day)	200	U.S. EPA 1991a (pg. 15)
Indoor Worker Soil Ingestion Rate (mg/day)	50	U.S. EPA 2001 (pg. 4-3)
Outdoor Worker Soil Ingestion Rate (mg/day)	100	U.S. EPA 1991a (pg. 15)
Recreator Soil Ingestion Rate - adult (mg/day)	100	U.S. EPA 1991a (pg. 15)
Recreator Soil Ingestion Rate - child (mg/day)	200	U.S. EPA 1991a (pg. 15)

(cont.) Inhalation, Ingestion, and Consumption Rates

Parameter (units)	Default	Information/Reference
Resident Soil Ingestion Rate - adult (mg/day)	100	U.S. EPA 1991a (pg. 15)
Resident Soil Ingestion Rate - child (mg/day)	200	U.S. EPA 1991a (pg. 15)
Composite Worker Soil Ingestion Rate (mg/day)	100	U.S. EPA 1991a (pg. 15)
Farmer Swine Ingestion Rate - adult (g/day)	92.5	U.S. EPA 2011 (Table 13-51)
Farmer Swine Ingestion Rate - child (g/day)	33.7	U.S. EPA 2011 (Table 13-51)
Recreator Surface Water Ingestion Rate - adult (L/hour)	0.071	Adult upper percentile from Table 3.5 of EFH 2011
Recreator Surface Water Ingestion Rate - child (L/hour)	0.12	Child upper percentile from Table 3.5 of EFH 2011
Resident Tapwater Ingestion - adult (L/day)	2.5	U.S. EPA 2011a, Tables 3-15 and 3-33; weighted average of 90th percentile consumer-only ingestion of drinking water (birth to <6 years)
Resident Tapwater Ingestion - child (L/day)	0.78	U.S. EPA 2011a, Tables 3-15 and 3-33; weighted average of 90th percentile consumer-only ingestion of drinking water (birth to <6 years)

Exposure Frequency, Exposure Duration, and Exposure Time Variables

Parameter (units)	Default	Information/Reference
Construction Worker Exposure Frequency (days/week)	5	U.S. EPA 2002 Exhibit 5-1
Construction Worker Exposure Duration (years)	1	U.S. EPA 2002 Exhibit 5-1
Farmer Exposure Duration (years)	40	U.S. EPA 2005 (Table 6-3)
Farmer Exposure Duration - adult (years)	34	U.S. EPA 1994a
Farmer Exposure Duration - child (years)	6	U.S. EPA 2005 (Table 6-3)
Indoor Worker Exposure Duration (years)	25	U.S. EPA 1991a (pg. 15)
Outdoor Worker Exposure Duration (years)	25	U.S. EPA 1991a (pg. 15)
Recreator Exposure Duration (years)	site-specific	U.S. EPA 2011a, Table 16-108; 90th percentile or current residence time.
Recreator Exposure Duration - adult (years)	site-specific	-
Recreator Exposure Duration - child (years)	site-specific	U.S. EPA 1991a, Pages 6 and 15
Resident Exposure Duration (years)	26	U.S. EPA 2011a, Table 16-108; 90th percentile or current residence time.
Resident Exposure Duration - adult (years)	20	ED_{res} (26 years) - $ED_{res\text{-}c}$ (6 years)
Resident Exposure Duration - child (years)	6	U.S. EPA 1991a, Pages 6 and 15
Composite Exposure Duration (years)	25	U.S. EPA 1991a (pg. 15)
Construction Worker Exposure Frequency (days/year)	250	U.S. EPA 2002 Exhibit 5-1
Farmer Exposure Frequency (days/year)	350	U.S. EPA 1991a (pg. 15)
Indoor Worker Exposure Frequency (days/year)	250	U.S. EPA 1991a (pg. 15)
Outdoor Worker Exposure Frequency (days/year)	225	U.S. EPA 1991a (pg. 15)
Recreator Exposure Frequency - (days/year)	site-specific	U.S. EPA 1991a (pg. 15)
Recreator Exposure Frequency - adult (days/year)	site-specific	U.S. EPA 1991a (pg. 15)
Recreator Exposure Frequency - child (days/year)	site-specific	U.S. EPA 1991a (pg. 15)
Resident Exposure Frequency - (days/year)	350	U.S. EPA 1991a (pg. 15)
Resident Exposure Frequency - adult (days/year)	350	U.S. EPA 1991a (pg. 15)
Resident Exposure Frequency - child (days/year)	350	U.S. EPA 1991a (pg. 15)
Composite Worker Exposure Frequency (days/year)	250	U.S. EPA 1991a (pg. 15)

(cont.) Exposure Frequency, Exposure Duration, and Exposure Time Variables

Parameter (units)	Default	Information/Reference
Construction Worker Exposure Time (hours/day)	8	Eight Hours per 24 hour Day
Farmer Exposure Time (hours/day)	24	24 Hours per 24 hour Day
Farmer Exposure Time - away (hours/day)	1.83	U.S. EPA 2011 (Tables 16-20 and 16-24 total of time in vehicles, near vehicles and outdoors other than near residence 25^{th}%)
Farmer Exposure Time - indoor (hours/day)	10.0	1440 hrs/day - ($ET_{f\text{-}o}$ + $ET_{f\text{-}a}$)
Farmer Exposure Time - outdoor (hours/day)	12.167	U.S. EPA 2011 (Table 16-20 95^{th}%))
Indoor Worker Exposure Time (hours/day)	8	Eight Hours per 24 hour Day
Outdoor Worker Exposure Time (hours/day)	8	Eight Hours per 24 hour Day
Recreator Exposure Time (hours/day)	site-specific	
Recreator Exposure Time - adult (hours/day)	site-specific	
Recreator Exposure Time - child (hours/day)	site-specific	
Resident Exposure Time (hours/day)	24	24 Hours per 24 hour Day
Resident Exposure Time - indoor (hours/day)	16.416	U.S. EPA 2011 (Table 16-16 50^{th}%)
Resident Exposure Time - outdoor (hours/day)	1.752	U.S. EPA 2011 (Table 16-20 50^{th}%))
Composite Worker Exposure Time (hours/day)	8	Eight Hours per 24 hour Day
Number of bathing events per day - adult recreator (events/day)	site-specific	-
Number of bathing events per day - child recreator (events/day)	site-specific	U.S. EPA 1991a, Pages 6 and 15
Number of bathing events per day - adult resident (events/day)	1	
Number of bathing events per day - child resident (events/day)	1	
Construction Worker Exposure Frequency (weeks/year)	50	U.S. EPA 2002 Exhibit 5-1

Soil to Groundwater SSL Factor Variables		
Parameter (units)	**Default**	**Information/Reference**
Target soil leachate concentration (pCi/L)	nonzero MCL or RSL × DAF	U.S. EPA. 2002 Equation 4-14
mixing zone depth (m)	site-specific	U.S. EPA. 2002 Equation 4-12
aquifer thickness (m)	site-specific	U.S. EPA. 2002 Equation 4-10
Dilution attenuation factor (unitless)	1 (or site-specific)	U.S. EPA. 2002 Equation 4-11
depth of source (m)	site-specific	U.S. EPA. 2002 Equation 4-10
Exposure duration	70	U.S. EPA. 2002 Equation 4-14
hydraulic gradient (m/m)	site-specific	U.S. EPA. 2002 Equation 4-11
Infiltration Rate (m/year)	0.18	U.S. EPA. 2002 Equation 4-11
aquifer hydraulic conductivity (m/year)	site-specific	U.S. EPA. 2002 Equation 4-11
soil-water partition coefficient (L/kg)	= K_{oc}*f_{oc} for organics	U.S. EPA. 2002 Equation 4-10
source length parallel to ground water flow(m)	site-specific	U.S. EPA. 2002 Equation 4-11
total soil porosity(L_{pore}/L_{soil})	= 1-(ρ_b/ρ_s)	U.S. EPA. 2002 Equation 4-10
air-filled soil porosity (L_{air}/L_{soil})	= n-θ_w	U.S. EPA. 2002 Equation 4-10
water-filled soil porosity (L_{water}/L_{soil})	0.3	U.S. EPA. 2002 Equation 4-10
dry soil bulk density (kg/L)	1.5	U.S. EPA. 2002 Equation 4-10
soil particle density (Kg/L)	2.65	U.S. EPA. 2002 Equation 4-10

Wind Particulate Emission Factor Variables		
Parameter (units)	**Default**	**Information/Reference**
Dispersion constant unitless	PEF and region-specific	U.S. EPA 2002 Exhibit D-2
Areal extent of the site or contamination (acres)	0.5 (range 0.5 to 500)	U.S. EPA 2002 Exhibit D-2
Dispersion constant unitless	PEF and region-specific	U.S. EPA 2002 Exhibit D-2
Dispersion constant unitless	PEF and region-specific	U.S. EPA 2002 Exhibit D-2
Function Dependent on 0.886 × (U_t/U_m) (unitless)	0.194	U.S. EPA. 1996, Appendix D Table 2
Inverse of the Mean Concentration at the Center of a 0.5-Acre-Square Source (g/m^2-s per kg/m^3)	93.77 (region-specific)	U.S. EPA 2002 Exhibit D-2
Mean Annual Wind Speed (m/s)	4.69	U.S. EPA. 1996, Appendix D Table 2
Equivalent Threshold Value of Wind Speed at 7m (m/s)	11.32	U.S. EPA. 1996, Appendix D Table 2
Fraction of Vegetative Cover (unitless)	0.5	U.S. EPA. 2002 Equation 4-5
Particulate Emission Factor - Minneapolis (m^3/kg)	1.36 x 10^9(region-specific)	U.S. EPA 2002 Exhibit D-2, This factor represents an estimate of the relationship between soil contaminant concentrations and the concentration of these contaminants in air as a consequence of particle suspension

Mechanical Particulate Emission Factor Variables from Standard Unpaved Road Vehicle Traffic

Parameter (units)	Default	Information/Reference
Dispersion constant unitless	12.9351	U.S. EPA 2002 Equation 5-6
Surface area of contaminated road segment (m^2)	($A_R = L_R$ x W_R x 0.092903m^2 /ft^2)	U.S. EPA 2002 Equation 5-5
Areal extent of site surface soil contamination (acres)	0.5 (range 0.5 to 500)	U.S. EPA 2002 Equation 5-6
Dispersion constant unitless	5.7383	U.S. EPA 2002 Equation 5-6
Dispersion constant unitless	71.7711	U.S. EPA 2002 Equation 5-6
Dispersion correction factor (unitless)	0.185	U.S. EPA 2002 Equation E-16
Length of road segment (ft)	Site-specific	U.S. EPA 2002 Equation 5-5
Number of days with at least 0.01 inches of precipitation (days/year)	Site-specific	U.S. EPA 2002 Exhibit 5-2
Inverse of the ratio of the 1-h geometric mean concentration to the emission flux along a straight road segment bisecting a square site (g/m^2-s per kg/m^3)	23.02 (for 0.5-acre site)	U.S. EPA 2002 Equation 5-5
Total time over which construction occurs (s)	site-specific	U.S. EPA 2002 Equation 5-5
Mean vehicle weight (tons)	(number of cars x tons/car + number of trucks x tons/truck) / total vehicles)	U.S. EPA 2002 Equation 5-5
Width of road segment (ft)	20	U.S. EPA 2002 Equation E-18
Sum of fleet vehicle kilometers traveled during the exposure duration (km)	∑VKT = total vehicles x distance (km/day) x frequency (weeks/year) x (days/year)	U.S. EPA 2002 Equation 5-5
Particulate Emission Factor - subchronic (m^3/kg)	(site-specific)	U.S. EPA 2002 Equation 5-5

Mechanical Particulate Emission Factor Variables from Other Construction Activities

Parameter (units)	Default	Information/Reference
PM_{10} particle size multiplier (unitless)	0.35	U.S. EPA 2002 Equation E-21
PM_{10} scaling factor (unitless)	0.60	U.S. EPA 2002 Equation E-23
PM_{10} scaling factor (unitless)	0.75	U.S. EPA 2002 Equation E-22
Dispersion constant unitless	2.4538	U.S. EPA 2002 Equation E-15
Areal extent of dozing (acres)	Site-specific	
Areal extent of tilling (acres)	Site-specific	U.S. EPA 2002 Equation E-24
Areal extent of excavation (m^2)	(range 0.5 to 500)	U.S. EPA 2002 Equation E-21
Areal extent of site surface soil contamination (acres)	(range 0.5 to 500)	U.S. EPA 2002 Equation E-15
Areal extent of site surface soil contamination (m^2)	(range 0.5 to 500)	U.S. EPA 2002 Equation E-20
Dispersion constant unitless	17.5660	U.S. EPA 2002 Equation E-15
Dozer blade length (m)	Site-specific	U.S. EPA 2002 Page E-28
Grader blade length (m)	Site-specific	U.S. EPA 2002 Page E-28
Dispersion constant unitless	189.0426	U.S. EPA 2002 Equation E-15
Average depth of excavation (m)	Site-specific	U.S. EPA 2002 Equation E-21
Exposure duration (years)	Site-specific	U.S. EPA 2002 Equation E-20
Function Dependent on $0.886 \times (U_t/U_m)$ (unitless)	0.194	U.S. EPA. 1996, Appendix D Table 2
Dispersion correction factor (unitless)	Site-specific	U.S. EPA 2002 Equation E-16
Total time-averaged PM_{10} unit emission flux for construction activities other than traffic on unpaved roads	Site-specific	U.S. EPA 2002 Equation E-25
Unit mass emitted from dozing operations (g)	site-specific	U.S. EPA 2002 Equation E-22
Unit mass emitted from excavation soil dumping (g)	site-specific	U.S. EPA 2002 Equation E-21
Unit mass emitted from grading operations (g)	site-specific	U.S. EPA 2002 Equation E-23
Gravimetric soil moisture content (%)	7.9 (mean value for overburden)	U.S. EPA 2002 Equation E-22
Gravimetric soil moisture content (%)	12 (mean value for municipal landfill cover)	U.S. EPA 2002 Equation E-21
Unit mass emitted from wind erosion (g)	site-specific	U.S. EPA 2002 Equation E-20
Unit mass emitted from tilling operations (g)	site-specific	U.S. EPA 2002 Equation E-24
Number of times site is dozed (unitless)	Site-specific	U.S. EPA 2002 Equation E-22
Number of times soil is dumped (unitless)	2	U.S. EPA 2002 Equation E-21
Number of times site is graded (unitless)	Site-specific	U.S. EPA 2002 Equation E-23
Number of times soil is tilled (unitless)	2	U.S. EPA 2002 Equation E-24
Inverse of the ratio of the 1-h. geometric mean air concentration and the emission flux at the center of the square emission source (g/m^2-s per kg/m^3)	Site-specific	U.S. EPA 2002 Equation E-15
Average dozing speed (kph)	11.4	U.S. EPA 2002 Equation E-22
Soil silt content (%)	6.9	U.S. EPA 2002 Equation E-22
Average grading speed (kph)	11.4	U.S. EPA 2002 Equation E-23
Soil silt content (%)	18	U.S. EPA 2002 Equation E-24
Mean Annual Wind Speed (m/s)	4.69	U.S. EPA. 1996, Appendix D Table 2
Equivalent Threshold Value of Wind Speed at 7 m (m/s)	11.32	U.S. EPA. 1996, Appendix D Table 2
Fraction of Vegetative Cover (unitless)	0	U.S. EPA 2002 Equation E-20
In situ soil density (includes water) (Mg/m^3)	1.68	U.S. EPA 2002 Equation E-21
Sum of dozing kilometers traveled (km)	Site-specific	U.S. EPA 2002 Equation E-22
Sum of grading kilometers traveled (km)		U.S. EPA 2002 Equation E-23
Areal extent of grading (acres)	Site-specific	
Particulate Emission Factor - subchronic (m^3/kg)	(site-specific)	U.S. EPA 2002 Equation E-26

2.4 PRG/DCC References:

ANL (2001). User's Manual for RESRAD Version 6. Argonne National Laboratory, Argonne, IL. ANL/EAD-4

AMEC (2014). Uptake of Gaseous Carbon-14 in the Biosphere: Development of an Assessment Model. AMEC/004041/007, Issue 2.

Calabrese E.J., Barnes R., Stanek III E.J., Pastides H., Gilbert CE, Veneman P., Wang XR, Lasztity A., and Kostecki P.T. (1989); How much soil do young children ingest: an epidemiologic study. Regul Toxicol Pharmacol: 10(2):123-137.

Davis, S; Waller, P; Buschbom, R; Ballou, J; White, P. (1990). Quantitative estimates of soil ingestion in normal children between the ages of 2 and 7 years: Population-based estimates using aluminum, silicon, and titanium as soil tracer elements. Arch Environ Health 45: 112-122.

Environment Agency (E.A.) (2006). Initial radiological assessment methodology - part 2 methods and input data. United Kingdom. SC030162/SR2.

Environment Agency (E.A.) (2009). Updated technical background to the CLEA model. United Kingdom. SC050021/SR3. pg. 97 and pg. 100.

Etnier 1980. Till, J. E., H. R. Meyer, E. L. Etnier, E. S. Bomar, R. D. Gentry, G. G. Killough, P. S. Rohwer, V. J. Tennery, and C. C. Travis Tritium-An Analysis of Key Environmental and Dosimetric Questions. ORNL/TM-6990. pg 15.

Hinton, T. G. 1992. Contamination of plants by resuspension: a review, with critique of measurement methods. Sci. Total Environ. 121:171-193

Hoffman, David J.; Rattner, Barnett A.; Burton, G. Allen jr.; Cairns, John jr. 2003. Handbook of Ecotoxicology: Second Edition. Lewis Publishers.

IAEA 1994. Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments. International Atomic Energy Agency. TRS-364

IAEA 2009. Quantification of Radionuclide Transfer in Terrestrial and Freshwater Environments for Radiological Assessments. International Atomic Energy Agency. TECDOC1616.

IAEA 2010. Technical Report Series No. 472: Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments. International Atomic Energy Agency. TRS-472

ICRP 2008. Nuclear Decay Data for Dosimetric Calculations. ICRP Publication 107. Ann. ICRP 38 (3).

Lyons, Robert K.; Machen, Rick; Forbes, T.D.A. 1999 Understanding Forage Intake in Range Animals AgriLIFE Extension. Texas A&M.

Lugo, A. E.; Brown, S.L.; Dodson, R.; Smith, T.S.; and Shugart, H.H. (1999); The Holdridge life zones of the conterminous United States in relation to ecosystem mapping ; Journal of Biogeography, 26, 1025-1038

MILLER Ch. W. (1980): An analysis of measured values for the fraction of a radiocative aerosol intercepted by vegetation. Health Physics, 38: 705 - 712.

NCRP (1996). Screening Models for Releases of Radionuclides to Atmosphere, Surface Water, and Ground, Vols. 1 and 2, NCRP Report No. 123. National Council on Radiation Protection and Measurements. http://www.ncrp.com/rpt123.html

NEC. Swine Nutrition Guide. Cooperative Extension Service / South Dakota State University and University of Nebraska / U.S. Department of Agriculture. Nebraska Cooperative Extension EC 95-273-C.

The pig water ingestion numbers are derived from the USDA "Swine Nutrition Guide" and the EPA Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities, found here. USDA assumes a pig consumes 1/4 to 1/3 gallons of water for every pound of dry feed. The midpoint of this range (7/24 gallons of water per 1 lbs. of dry feed) was used with the default dry feed, (4.7 kg) from the U.S. EPA, to come up with 3 gallons (11.4 L) per day default water intake.

NRC 1994. Nutrient Requirements of Poultry: Ninth Revised Edition. Washington, DC: The National Academies Press, 1994.

OMAFRA (2015). Water Requirements of Livestock. Order Number 07-023. July, 2015.

ORNL (2014a). Area Correction Factors for Contaminated Soil for Use in Risk and Dose Assessment Models and appendix. Center for Radiation Protection Knowledge. September 2014.

ORNL (2014b). Gamma Shielding Factors for Soil Covered Contamination for Use in Risk and Dose Assessment Models and appendix. Center for Radiation Protection Knowledge. September 2014.

ORNL (2014c). Calculation of Slope Factors and Dose Coefficients and appendix. Center for Radiation Protection Knowledge. September 2014.

ORNL (2016). Biota Modeling in EPA's Preliminary Remediation Goal and Dose Compliance Concentration Calculators for Use in EPA Superfund Risk Assessment: Explanation of Intake Rate Derivation, Transfer Factor Compilation, and Mass Loading Factor Sources Center for Radiation Protection Knowledge. November 2016.

Pinder, J. E. ,. I., and K. W. McLeod. (1989). Mass loading of soil particles on plant surfaces, Health Phys. 57:935-942.

Tarr, Brian. Guidelines to Feeding and Management of Dairy Goats Nutrifax. Shur Gain.

U.S. EPA. (1988). Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion. Federal Guidance Report No. 11. Office of Radiation Programs, Washington, DC. EPA-520/1-88-020. http://www.epa.gov/radiation/federal/index.html

U.S. EPA (1989). U.S. Environmental Protection Agency (U.S. EPA). Risk assessment guidance for Superfund. Volume I: Human health evaluation manual (Part A). Interim Final. Office of Emergency and Remedial Response. EPA/540/1-89/002.

U.S. EPA (1990). Interim Final Methodology for Assessing Health Risks Associated with Indirect Exposure to Combustor Emissions. Environmental Criteria and Assessment Office. ORD. EPA-600-90-003. January.

U.S. EPA (1991a). U.S. Environmental Protection Agency (U.S. EPA). Human health evaluation manual, supplemental guidance: "Standard default exposure factors". OSWER Directive 9285.6-03.

U.S. EPA (1991b). Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part B, Development of Risk-Based Preliminary Remediation Goals). Office of Emergency and Remedial Response. EPA/540/R-92/003. December 1991

U.S. EPA. (1993). External Exposure to Radionuclides in Air, Water, and Soil. Federal Guidance Report No. 12. Office of Radiation and Indoor Air, Washington, DC. EPA 402-R-93-081. http://www.epa.gov/radiation/federal/index.html

U.S. EPA. (1994a). Estimating Exposure to Dioxin-like Components - Volume III: Site-Specific Assessment Procedure. Review Draft. Office of Research and Development. Washington D.C. EPA/600/6-88/005Cc. June. (Also see U.S. EPA. 1994c for direct link to Table) http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=34762

U.S. EPA (1994b). Radiation Site Cleanup Regulations: Technical Support Documents for the Development of Radiation Cleanup Levels for Soil - Review Draft. Office of Radiation and Indoor Air, Washington, DC. EPA 402-R-96-011A. PDF document View Appendix C here.

U.S. EPA. (1994c). Revised Draft Guidance for Performing Screening Level Risk Analyses at Combustion Facilities Burning Hazardous Wastes. Attachment C, Draft Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities. Office of Emergency and Remedial Response. Office of Solid Waste. December 14. http://www.epa.gov/osw/hazard/tsd/td/combust/finalmact/ssra/05hhrapapc.pdf

U.S. EPA. (1996a). Soil Screening Guidance: User's Guide. Office of Emergency and Remedial Response. Washington, DC. OSWER No. 9355.4-23 http://www.epa.gov/superfund/health/conmedia/soil/index.htm

U.S. EPA. (1996b). Soil Screening Guidance: Technical Background Document. Office of Emergency and Remedial Response. Washington, DC. OSWER No. 9355.4-17A http://www.epa.gov/superfund/health/conmedia/soil/index.htm

U.S. EPA. (1997a). Exposure Factors Handbook. Office of Research and Development, Washington, DC. EPA/600/P-95/002Fa.

U.S. EPA. (1997b). Parameter Guidance Document. National Center for Environmental Assessment, NCEA-0238.

U.S. EPA. (1998). Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities. Office of Solid Waste, Washington, DC. EPA530-D-98-001A. A secure PDF can be downloaded here.

U.S. EPA. (1999a). Data Collection for the Hazardous Waste Identification Rule. Office of Solid Waste, Washington, DC. http://www.epa.gov/osw/hazard/wastetypes/wasteid/hwirwste/risk.htm The section on cattle fodder, soil and water intakes is here.

U.S. EPA (1999b). Volume II, "Review of Geochemistry and Available Kd Values for Cadmium, Cesium, Chromium, Lead, Plutonium, Radon, Strontium, Thorium, Tritium (3H), and Uranium. Office of Radiation and Indoor Air. Washington, DC. EPA 402-R-99-004B, August 1999. http://www.epa.gov/cgi-bin/claritgw?op-Display&document=clserv:OAR:0232;&rank=4&template=epa

U.S. EPA (1999c). Cancer Risk Coefficients for Environmental Exposure to Radionuclides. Federal Guidance Report No. 13. Office of Radiation and Indoor Air. EPA 402-R-99-001. September 1999. http://www.epa.gov/radiation/federal/index.html

U.S. EPA. (2000a). Soil Screening Guidance for Radionuclides: User's Guide. Office of Emergency and Remedial Response and Office of Radiation and Indoor Air. Washington, DC. OSWER No. 9355.4-16A http://www.epa.gov/superfund/health/contaminants/radiation/radssg.htm

U.S. EPA. (2000b). Soil Screening Guidance for Radionuclides: Technical Background Document. Office of Emergency and Remedial Response and Office of Radiation and Indoor Air. Washington, DC. OSWER No. 9355.4-16 http://www.epa.gov/superfund/health/contaminants/radiation/radssg.htm

U.S. EPA (2002). Role of Background in the CERCLA Cleanup Program. Office of Solid Waste and Emergency Response, April 26, 2002, OSWER 9285.6-07P

U.S. EPA (2002). Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites. OSWER 9355.4-24. December 2002. http://www.epa.gov/superfund/health/conmedia/soil/index.htm

U.S. EPA (2002). Simulating Transport in the Unsaturated Zone: Evaluation and Sensitivity Analyses of Select Computer Models.

U.S. EPA. (2005). Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities. Office of Solid Waste, Washington, DC. http://www.epa.gov/osw/hazard/tsd/td/combust/risk.htm. The pdf is available here.

U.S. EPA. (2011). Exposure Factors Handbook 2011 Edition (Final). National Center for Environmental Assessment, Office of Research and Development. Washington D.C.

van Wijnen J.H., Clausing P., and Brunekreef B. (1990); Estimated soil ingestion by children. Environ Res: 51(2): 147-162.

III. Residual Radioactive Material Guideline (RESRAD-ONSITE)

RESidual RADioactive material guidelines (RESRAD-ONSITE) is a computer model developed by Argonne National Laboratory for the U.S. Department of Energy (DOE) to calculate site-specific guidelines, radiation doses and excess lifetime cancer risk to a receptor chronically exposed on-site to residual radioactive materials (Figure 3). Although DOE is not regulating non-DOE sites, RESRAD-ONSITE is included in this study, since NRC recommendeds its use for NRC licensed sites as well as NRC's DandD code. RESRAD-ONSITE was first issued in 1989 and updated last in 2016. RESRAD-ONSITE can be downloaded at: http://www.evs.anl.gov/resrad/.

3.1 RESRAD-ONSITE Exposure Scenarios and Pathways

RESRAD-ONSITE has major exposure pathways; direct exposure to external radiation from the contaminated soil material; Internal exposure from inhalation of airborne radionuclides; Internal exposure from inhalation of radon progeny; and internal exposure from ingestion of: plant foods grown in the contaminated soil and irrigated with contaminated water, meat and milk from livestock fed with contaminated fodder and water, drinking water from a contaminated well or pond, fish from a contaminated pond, and contaminated soil.

3.2 RESRAD-ONSITE Recommended Default Input Parameters

Contaminated Zone		
Parameter	**Default**	**Information/Reference**
Area of contaminated zone (m^2)	1.0E+04	Area in which contains all the soils samples with radionuclide concentrations that are clearly (2 standard deviations) above background. This area is assumed to be circular for modeling purposes.
Thickness of contaminated zone (m)	2.0E+00	Thickness of the area considered to be the contaminated zone.
Length parallel to aquifer flow (m)	1.0E+02	This length is the distance between two parallel lines that are perpendicular to the direction of aquifer flow, one at the upgradient edge of the contaminated zone, the other at the downgradient edge.

Cover/Hydrology		
Parameter	**Default**	**Information/Reference**
Cover depth (m)	0.0E+00	The cover depth is the distance from the ground surface to the location of the uppermost soil sample with radionuclide concentrations that are clearly above background.
Density of cover material (g/cm3)	1.5E+00	The density is the ratio of the mass of a material to its volume.
Cover depth erosion rate (m/yr)	1.0E-03	The cover depth erosion rate is the rate at which soil is removed by erosion.
Density of contaminated zone (g/cm3)	1.5E+00	The density is the ratio of the mass of a material to its volume.
Contaminated zone erosion rate (m/yr)	1.0E-03	The contaminated erosion rate is the rate at which soil is removed by erosion. This parameter is only in effect when the cover depth equals zero.
Contaminated zone total porosity	4.0E-01	Total porosity of a porous medium is the ratio of the pore volume to the total volume of a representative sample.
Contaminated zone field capacity	2.0E-01	Effective porosity of a porous medium is the ratio of the part of the pore volume where water can circulate to the total volume of a representative sample. Effective porosity should not be greater than total porosity.
Contaminated zone hydraulic conductivity (m/yr)	1.0E+01	This value reflects the rate at which groundwater will move through soil.
Contaminated zone b parameter	5.3E+00	The b parameter is a hydrological parameter used to evaluate the saturation ratio.
Average annual wind speed (m/sec)	2.0E+00	The average annual wind speed is the overall average of the wind speed, measured near the surface in a one-year period.
Humidity in air (g/cm3)	8.0E+00	This parameter is only relevant to the Tritium model
Evapotranspiration coefficient	5.0E-01	The evapotranspiration coefficient represents the total volume of water that changes phase, that is, from the liquid or solid state to the gaseous state, near the ground surface and is transferred to the atmosphere during a fixed period of time.
Precipitation (m/yr)	1.0E+00	The precipitation rate is the average volume of water in the form of rain, snow, hail, or sleet that falls per unit of area and per unit of time at the site.
Irrigation (m/yr)	2.0E-01	The irrigation rate is the amount of water that is added to the soil at the site as a artificial water supply in order to permit agricultural use of the land.
Irrigation mode	overhead	
Runoff coefficient	2.0E-01	Runoff coefficient is the fraction of the average annual precipitation that does not infiltrate into the soil and is not transferred back into the atmosphere through evapotranspiration.
Watershed area for nearby stream or pond (m2)	1.0E+06	The watershed is a region contoured by an imaginary line connecting ridges or summits of high land and drained by or draining into a river, river system, or a body of water.
Accuracy for water/soil computations	1.0E-03	No information available

Saturated Zone		
Parameter	**Default**	**Information/Reference**
Density of saturated zone (g/cm3)	1.5E+00	The density is the ratio of the mass of a material to its volume. The saturated zone is the layer of the uncontaminated zone that lies below the contaminated zone and the unsaturated zone but within the water table.
Saturated zone total porosity	4.0E-01	Total porosity of a porous medium is the ratio of the pore volume to the total volume of a representative sample.
Saturated zone effective porosity	2.0E-01	Effective porosity of a porous medium is the ratio of the part of the pore volume where water can circulate to the total volume of a representative sample. Effective porosity should not be greater than total porosity.
Saturated zone field capacity	2.0E-01	Field capacity is the volumetric moisture content of soil at which (free) gravity drainage ceases. This is the amount of moisture that will be retained in a column of soil against the force of gravity. The field capacity sets the lower limit of the volumetric water content and is used to replace the calculated value when the calculated value is smaller
Saturated zone hydraulic conductivity (m/yr)	1.0E+02	Hydraulic conductivity is the measure of the soil's ability to transmit water when submitted to a hydraulic gradient.
Saturated zone hydraulic gradient	2.0E-02	The hydraulic gradient is the change in hydraulic head per unit of distance of the groundwater flow in a given direction.
Saturated zone b parameter	5.3E+00	The b parameter is a hydrological parameter used to evaluate the saturation ratio.
Water table drop rate (m/yr)	1.0E-03	The water table drop rate is the rate at which the depth of the water table is lowered.
Well pump intake depth (m below water table)	1.0E+01	The well-pump intake depth is the screened depth of a well within the aquifer (the saturated zone).
Model: Nondispersion (ND) or Mass- Balance (MB)	ND	The choice of ND (non-dispersion) or MB (mass balance) selects which of two models used for water/soil concentration ratio calculations. Selecting 0 uses the ND model where selecting 1 uses the MB model. The MB model is not recommended for contaminated zone.
Well pumping rate (m3/yr)	2.5E+02	The well pumping rate is the total volume of water obtained annually from the well for use by humans and livestock.

Unsaturated		
Parameter	**Default**	**Information/Reference**
Number of unsaturated zone strata	1.0E+00	Number of unsaturated zones used in the model.
Unsat. zone 1, thickness (m)	4.0E+00	The unsaturated zone #1 is the 1st layer of the uncontaminated zone that lies below the contaminated zone and above the saturated zone.
Unsat. zone 1, soil density (g/cm3)	1.5E+00	The density is the ratio of the mass of a material to its volume.
Unsat. zone 1, total porosity	4.0E-01	Total porosity of a porous medium is the ratio of the pore volume to the total volume of a representative sample.
Unsat. zone 1, effective porosity	2.0E-01	Effective porosity of a porous medium is the ratio of the part of the pore volume where water can circulate to the total volume of a representative sample. Effective porosity should not be greater than total porosity.
Unsat. zone 1, field capacity	2.0E-01	Field capacity is the volumetric moisture content of soil at which (free) gravity drainage ceases. This is the amount of moisture that will be retained in a column of soil against the force of gravity.
Unsat. zone 1, soil-specific b parameter	5.3E+00	The b parameter is a hydrological parameter used to evaluate the saturation ratio.
Unsat. zone 1, hydraulic conductivity (m/yr)	1.0E+01	Hydraulic conductivity is the measure of the soil's ability to transmit water when submitted to a hydraulic gradient.
Unsat. zone 2, thickness (m)	0.0E+00	The unsaturated zone #2 is the 2nd layer of the uncontaminated zone that lies below the contaminated zone and above the saturated zone.
Unsat. zone 2, soil density (g/cm3)	1.5E+00	The density is the ratio of the mass of a material to its volume.
Unsat. zone 2, total porosity	4.0E-01	Total porosity of a porous medium is the ratio of the pore volume to the total volume of a representative sample.
Unsat. zone 2, effective porosity	2.0E-01	Effective porosity of a porous medium is the ratio of the part of the pore volume where water can circulate to the total volume of a representative sample. Effective porosity should not be greater than total porosity.
Unsat. zone 2, field capacity	2.0E-01	Field capacity is the volumetric moisture content of soil at which (free) gravity drainage ceases. This is the amount of moisture that will be retained in a column of soil against the force of gravity.
Unsat. zone 2, soil-specific b parameter	5.3E+00	The b parameter is a hydrological parameter used to evaluate the saturation ratio.
Unsat. zone 2, hydraulic conductivity (m/yr)	1.0E+01	Hydraulic conductivity is the measure of the soil's ability to transmit water when submitted to a hydraulic gradient.

Soil Concentrations - Transport		
Parameter	**Default**	**Information/Reference**
Distribution coefficients for all isotopes: Contaminated zone (cm3/g) Unsaturated zone (cm3/g) Saturated zone (cm3/g)	Radionuclide-specific	Distribution coefficients are used to develop the leach- rate constants between the surface soil layer, the unsaturated soil layer and the aquifer.
Leach rate (/yr)	0.0E+00	
Solubility constant	0.0E+00	

Soil Concentrations		
Parameter	Default	Information/Reference
Basic radiation dose limit (mrem/yr)	2.5E+01	NRC guideline of 25 mrem/yr
Time since placement of material (yr)	0.0E+00	This is the elapsed time, in years, between the placement of radioactive materials on-site and the performance of radiological survey. It is possible that on-site radioactive materials originated from different sources and have different placement times

Occupancy		
Parameter	**Default**	**Information/Reference**
Inhalation rate (m3/yr)	8.4E+04	Inhalation rate determined for subsistence farmer who works land and has primary residence on site.
Mass loading for inhalation (g/m3)	1.0E-04	The mass loading parameter is the concentration of soil particles in the air
Exposure duration (year)	3.0E+01	The exposure duration is the span of time, in years, during which an individual is expected to spend time on the site. The default value in RESRAD is 30 years.
Shielding factor, inhalation	4.0E-01	The shielding factor describes the effect of the building structure on the level of gamma radiation and/or contaminated dust existing indoors. Shielding factor is dependent on exposure time.
Shielding factor, external gamma	7.0E-01	The shielding factor describes the effect of the building structure on the level of gamma radiation and/or contaminated dust existing indoors. Shielding factor is dependent on exposure time.
Fraction of time spent indoors	6.55E-01	The fraction of time spent indoors onsite is the average fraction of time in a year during which an individual stays inside a house or a building on the contaminated site.
Fraction of time spent outdoors (on site)	2.5E-01	The fraction of time spent outdoors onsite is the average fraction of time in a year during which an individual stays outdoors on the site.
Shape factor flag, external gamma	1.0E+00	Setting the shape factor to -1 shows that the contaminated zone is not circular. The receptor was placed in the approximate center of a rectangular area.

Ingestion, Dietary		
Parameter	**Default**	**Information/Reference**
Fruits, vegetables and grain consumption (kg/yr)	1.6E+02	Consumption rate of fruits, vegetables and grain
Leafy vegetable consumption (kg/yr)	1.4E+01	Consumption rate of leafy vegetables.
Milk consumption (L/yr)	9.2E+01	Consumption rate of milk.
Meat and poultry consumption (kg/yr)	6.3E+01	Consumption rates of meat and poultry.
Fish consumption (kg/yr)	5.4E+00	Consumption rate of fish.
Other seafood consumption (kg/yr)	9.0E-01	Other seafood (lobsters, oysters, scallops, shrimp and other non-fish).
Soil ingestion rate (g/yr)	3.7E+01	The soil ingestion rate is the direct accidental ingestion rate of soil material or soil dust.
Drinking water intake (L/yr)	5.1E+02	Average amount of water consumed by an adult.
Contamination fraction of drinking water	1.0E+00	Fraction of substance used that originates from the contaminated site. Only used when applicable pathway is on. For example, for a scenario that does obtain drinking water from onsite, this value is zero. Off-site water is assumed to be uncontaminated
Contamination fraction of household water	1.0E+00	Fraction of substance used that originates from the contaminated site.
Contamination fraction of livestock water	1.0E+00	Fraction of substance used that originates from the contaminated site.
Contamination fraction of irrigation water	1.0E+00	Fraction of substance used that originates from the contaminated site.
Contamination fraction of aquatic food	5.0E-01	Fraction of substance used that originates from the contaminated site. Only in effect when the aquatic pathway is turned on.
Contamination fraction of plant food	- 1.0E+00	Fraction of substance used that originates from the contaminated site. Only in effect when plant ingestion pathway is turned on.
Contamination fraction of meat	- 1.0E+00	Fraction of substance used that originates from the contaminated site. Only in effect when meat ingestion pathway is turned on.
Contamination fraction of milk	- 1.0E+00	Fraction of substance used that originates from the contaminated site. Only in effect when milk ingestion pathway is turned on.

Ingestion, Non-Dietary		
Parameter	**Default**	**Information/Reference**
Livestock fodder intake for meat (kg/day)	6.8E+01	Rate at which beef animals intake fodder (forage, hay and grain).
Livestock fodder intake for milk (kg/day)	5.5E+01	Rate at which milk cows intake fodder (forage, hay, and grain).
Livestock water intake for meat (L/day)	5.0E+01	Rate at which beef animals intake water.
Livestock water intake for milk (L/day)	1.6E+02	Rate at which milk cows intake water.
Livestock soil intake (kg/day)	5.0E-01	Rate at which beef animals and milk cows intake soil.
Mass loading for foliar deposition (g/m3)	1.0E-04	
Depth of soil mixing layer (m)	1.5E-01	
Depth of roots (m)	9.0E-01	This parameter is the average root depth of various plants grown in the contaminated zone. The root depth varies for different plants.
Drinking water fraction from ground water	1.0E+00	Fraction of the drinking water obtained from onsite sources (ground water or surface water).
Household water fraction from ground water	1.0E+00	Fraction of the household water obtained from onsite sources (ground water or surface water)
Livestock water fraction from ground water	1.0E+00	Fraction of the livestock water obtained from onsite sources (ground water or surface water)
Irrigation fraction from ground water	1.0E+00	Percentage of irrigation water obtained from onsite ground water rather than on site surface water

Ingestion, Non-Dietary - Plant		
Parameter	**Default**	**Information/Reference**
Wet weight crop yield for Non-Leafy (kg/m^2)	7.0E-01	
Wet weight crop yield for Leafy (kg/m2)	1.5E+00	
Wet weight crop yield for Fodder (kg/m2)	1.1E+00	
Growing Season for Non-Leafy (years)	1.7E-01	
Growing Season for Leafy (years)	2.5E-01	
Growing Season for Fodder (years)	8.0E-02	
Translocation Factor for Non-Leafy	1.0E-01	The translocation fraction is the fraction of activity deposited on plant surfaces that reaches the edible parts of the non-leafy plant.
Translocation Factor for Leafy	1.0E+00	The translocation fraction is the fraction of activity deposited on plant surfaces that reaches the edible parts of the leafy plant.
Translocation Factor for Fodder	1.0E+00	The translocation fraction is the fraction of activity deposited on plant surfaces that reaches the edible parts of the (grains) plant.
Dry Foliar Interception Fraction for Non-Leafy	2.5E-01	The interception fraction as defined on is the fraction of deposited activity that is retained on plant surfaces.
Dry Foliar Interception Fraction for Leafy	2.5E-01	"
Dry Foliar Interception Fraction for Fodder	2.5E-01	"
Wet Foliar Interception Fraction for Non Leafy	2.5E-01	"
Wet Foliar Interception Fraction for Leafy	2.5E-01	"
Wet Foliar Interception Fraction for Fodder	2.5E-01	"
Weathering Removal Constant for Vegetation	2.0E+01	

Carbon-14		
Parameter	**Default**	**Information/Reference**
C-12 concentration in water (g/cm3)	2.0E-05	This set of parameters is only in effect if Carbon 14 is selected as a contaminant.
C-12 concentration in contaminated soil (g/g)	3.0E-03	"
Fraction of vegetation carbon from soil	2.0E-02	"
Fraction of vegetation carbon from air	9.8E-01	"
C-14 evasion layer thickness in soil (m)	3.0E-01	"
C-14 evasion flux rate from soil (1/sec)	7.0E-07	"
C-12 evasion flux rate from soil (1/sec)	1.0E-10	"
Fraction of grain in beef cattle feed	8.0E-01	"
Fraction of grain in milk cow feed	1.0E-01	"
DCF Corrections factor for gaseous forms of C14	8.9E+01	"

Storage Times Storage times of contaminated foodstuffs (days)		
Parameter	**Default**	**Information/Reference**
Fruits, non-leafy vegetables, and grain	1.4E+01	The storage time for fruits, non-leafy vegetables and grains is the time between harvest and consumption.
Leafy vegetables	1.0E+00	The storage time for leafy vegetables is the time between harvest and consumption.
Milk	1.0E+00	The storage time for milk is the time between acquisition and consumption.
Meat and poultry	2.0E+01	The storage time for meat and poultry is the time between slaughter and consumption.
Fish	7.0E+00	The storage time for fish is the time between catch and consumption.
Crustacea and mollusks	7.0E+00	The storage time for crustacea and mollusks is the time between catch and consumption.
Well water	1.0E+00	The storage time for well water is the time between acquisition and consumption.
Surface water	1.0E+00	The storage time for surface water is the time between acquisition and consumption.
Livestock fodder	4.5E+01	The storage time for livestock is the time between acquisition and consumption.

Radon		
Parameter	**Default**	**Information/Reference**
Thickness of building foundation (m)	1.5E-01	The thickness of the building foundation is the average thickness of the building shell structure in the subsurface of the soil.
Bulk density of building foundation 3	2.4E+00	The density of the foundation material.
Total porosity of the cover material	4.0E-01	Total porosity of a porous medium is the ratio of the pore volume to the total volume of a representative sample.
Total porosity of the building foundation	1.0E-01	Total porosity of a porous medium is the ratio of the pore volume to the total volume of a representative sample.
Volumetric water content of the cover material	5.0E-02	The volumetric water content in a porous medium is the ratio of the total volume of water present in the pore space to the total volume of the medium.
Volumetric water content of the foundation	3.0E-02	The volumetric water content in a porous medium is the ratio of the total volume of water present in the pore space to the total volume of the medium.
Diffusion coefficient for radon gas (m/sec):		The effective radon diffusion coefficient as the ratio of the radon flux across the pore area to the gradient of the radon concentration in the pore spaces.
in cover material	2.0E-06	The value is set to -1 so that the program will generate the value on the basis of the porosity and water content of the medium.
in foundation material	3.0E-07	The value is set to -1 so that the program will generate the value on the basis of the porosity and water content of the medium.
in contaminated zone soil	2.0E-06	The value is set to -1 so that the program will generate the value on the basis of the porosity and water content of the medium.
Radon vertical dimension of mixing (m)	2.0E+00	The radon vertical dimension of mixing parameter is the assumed height to which the radon emission from the ground surface is uniformly mixed in the outdoor air.
Average building air exchange rate (1/hr)	5.0E-01	The average building air exchange rate is the number of total volumes of air contained in the building that is being exchanged with outside air per unit of time.
Height of the building (room) (m)	2.5E+00	The height of the building (room) parameter is the average height of the living area of the building.
Building interior area factor	0.0E+00	The building interior area factor is the fraction of the floor area built on the contaminated area.
Building depth below ground surface (m)	-1.0E+00	The foundation depth below ground surface is the vertical distance in the soil from the very bottom of the basement floor slab to the ground surface.
Emanating power of Rn-222 gas	2.5E-01	The radon emanation coefficient is the fraction of the total amount of radon produced by radium decay that escapes from the soil particles and gets into the pores of the medium.
Emanating power of Rn-220 gas	1.5E-01	The radon emanation coefficient is the fraction of the total amount of radon produced by radium decay that escapes from the soil particles and gets into the pores of the medium.

Coefficients and Constants		
Parameter	**Default**	**Information/Reference**
Slope Factors	RN-specific	From EPA FGR-13 (Eckerman et al. 1999)
Morbidity and Mortality Risk Coefficients for External Exposure, Inhalation and Ingestion	RN-specific	From EPA FGR-11 (Eckerman et al. 1988)
External Dose Conversion Factors	RN-specific	From EPA FGR-12 (Eckerman and Ryman 1993)
Transfer Factors	RN-specific	Wang et al. (1993) (NCRP 1995).

3.3 RESRAD-ONSITE References

ANL (2001). *User's Manual for RESRAD Version 6*. Argonne National Laboratory, Argonne, IL. ANL/EAD-4

ANL (2015). *Data Collection Handbook to Support Modeling Impacts of Radioactive Material in Soil and Building Structures*, Argonne National Laboratory Argonne National Laboratory, Argonne, IL.

IV. NORM and LegacY Site Assessment (NORMALYSA)

NORMALYSA is risk assessment model developed by the International Atomic Energy Agency (IAEA) MODARIA I, Working Group 3, to assess radiological impacts arising from NORM and radioactively contaminated legacy sites to support remediation (Figure 6). NORMALYSA library of models consists of four components: Sources (radionuclide releases to ecosystems), Transport pathways, Receptors, and Dose (exposed human). NORMALYSA has no user's manual. Parameters can be obtained from the software.

4.1 NORMALYSA Exposure Scenarios and Pathways

SOURCE	TRANSPORT	RECEPTOR	DOSE
Tailing without cover	Groundwater	Cropland	Occupancy
Tailing with Cover	Surface runoff	Garden	Ingestion
	Atmospheric	Pastureland	Total
		Forest	
		Land	
		Marine	
		Freshwater body	
		Well	
		House	

4.2 NORMALYSA Recommended Default Input Parameters

Aquifer		
This module simulates radionuclide transport in the aquifer (flow tube) accounting for the advection, dispersion, radioactive decay and sorption “Transport" block is used to simulate RN migration in groundwater. The number of compartments N in transport block is determined automatically considering the accuracy of approximation of advection-dispersion fluxes (Parameter "dispersion accuracy" is used to control the accuracy of numerical approximations of advection-dispersion fluxes. The smaller is this parameter the larger is the number of compartments. The recommended value is 0.1-0.2).		
Parameter	**Default**	**Information/Reference**
Aquifer Kd (m^3/kgDW)	0.7	Sorption Kd values for aquifer material based on minimum values recommended in (IAEA, 2010).
Aquifer Material Bulk Density (kgDW/m^3)	1600	
Aquifer Porosity (unitless)	0.3	
Dispersion Accuracy (unitless)	0.1-0.2	Parameter controlling accuracy of approximation of dispersive flux in Transport_AQ block
Flow Tube Area (m^2)	4000	Flow tube (aquifer) cross-section area perpendicular to flow direction
Groundwater Flow Darcy Velocity (m/year)	10.0	Is used to calculate the input activity flux through inflow of contaminated groundwater from upstream direction.
Initial RN Concentration in Groundwater (Bq/m^3)	RN-specific	User Provided
Length of The Flow Tube (m)	100	
N Max (unitless)	100	Maximum number of cells in Transport_AQ block (unitless)
N Min (unitless)	5	Minimum number of cells in Transport_AQ block (unitless)
RN Concentration in Infiltration Water (Bq/m^3)	RN-specific	User Provided

Aquifer Mixing		
Aquifer mixing zone compartment (version 28.10.2013). This compartment is designed to represent a "transition compartment" between the Uns_Zone_TRANSPORT compartment and AQUIFER_TRANSPORT compartment. This compartment is used to "translate" vertical transport in the unsaturated zone to the horizontal transport in the aquifer (flow tube transport). The "Aquifer mixing" compartments simulates the aquifer zone immediately below the waste site, where contaminated infiltration flux from the unsaturated zone mixes with the groundwater in the aquifer. This "transition" compartment is particularly needed in a case the waste site has a large areal extent, while the aquifer has a low thickness		
Parameter	**Default**	**Information/Reference**
Aquifer Material Bulk Density, (kgDW/m^3)	1600	
Aquifer Material Kd, (m^3/kgDW)	0.7	Sorption Kd values for aquifer material based on minimum values recommended in (IAEA, 2010).
Aquifer Mixing Thickness, (m)	10	Thickness of the aquifer "mixing zone" below the waste site
Aquifer Porosity, (unitless)	0.3	
Groundwater Flow Darcy Velocity, (m/year)	10	
Infiltration Recharge Rate, (m/year)	0.3	
Initial RN Concentration in Groundwater, (Bq/m^3)		User Provided
Length of The Waste Site, (m)	200	
RN Concentration in Infiltration Water, (Bq/m^3)	RN-specific.	User Provided
RN Concentration in Inflowing Groundwater, (Bq/m^3)	RN-specific.	User Provided
Waste Site Area (m^2)	4000	

Atmosphere Chronic		
Parameter	**Default**	**Information/Reference**
Average Wind speed in Direction from Release Source to Recipient Object., (m/s)	1	Average wind speed in direction from release source to recipient object
Distance from Release Source to Geometric Center of Recipient Object.,(m)	1	
Normalized Radionuclide Concentration in The Atmospheric Air, (year/m^3)	0	
Normalized Rate of Deposition, (1/m^2)	0	
Release Rate at The Release Point (Bq/year)	1	Radionuclide Specific. User Provided

Atmosphere SR-19		
Module for the estimation of ground level air concentration (Bq/m^3) and deposition rates (Bq/m^2/year) at a Receptor. The approach of dispersion in the lee of an isolated point source when building wake effects are insignificant has been applied.		
Parameter	**Default**	**Information/Reference**
Distance from The Source to The Receptor, (m)	1000	
Dry Deposition Velocity, (m/day)	500	
Frequency at Which Wind Blows in A Year in The Direction of the Receptor Point	0.25	
Height at Which Radioactive Materials Are Released, (m)	0	
Release Rate at The Release Point, (Bq/s)	0	
Wet Deposition Velocity, (m/day)	500	
Wind at Release Height (m/s)	2	Geometric mean of the wind speed at the height of release for one representative year

Constants

Parameter	Default	Information/Reference
Conversion factor from ambient to effective dose	RN-specific	Conversion factor to obtain effective dose for reference person from ambient dose equivalent (BfS. 2011)
Dose Coefficient for Effective Dose by Ingestion, (Sv/Bq)	RN-specific	Committed dose over integration period. (BfS. 2011)
Dose coefficient for effective dose by inhalation (Sv/Bq)	RN-specific	Committed dose over integration period. Age dependent. (BfS. 2011)
Dose coefficient for effective dose by Radon inhalation, ((Sv*m^3)/(Bq*h))	RN-specific	Committed dose over integration period. Age dependent. (BfS. 2011)
Dose coefficient for effective dose from immersion in cloud ((Sv*m^3)/(Bq*h)	RN-specific	Assuming semi-infinite geometry Radionuclide Specific. User Provided
Dose coefficient for effective dose from immersion in water (Sv*h^{-1})/(Bq*m^{-3})	RN-specific	User Provided. Dose rate of external irradiation per unit concentration in water during swimming
Dose coefficient for effective dose from surface deposits, ((Sv*h^{-1})/(Bq*m^{-2}))	RN-specific	User Provided Assuming radionuclides distributed in 5 cm surface layer, Cs-137: 3.5E-14, Sr-90: 9.7E-18
Dose Coefficient for Effective Dose from Total Deposit, (Sv*m^3)/(Bq*h)	RN-specific	Assuming semi-infinite geometry with constant concentration
Equilibrium factor inside buildings	0.4	Equilibrium factor inside buildings between Rn-222 and its short-lived progeny for reference person at the exposure location (dimensionless) (BfS. 2011)
Equilibrium factor outdoors	0.4	Equilibrium factor outdoors between Rn-222 and its short lived progeny for reference person at the exposure location (dimensionless) (BfS. 2011)
Factor Cover Depth Fit Parameter A,	RN-specific	User Provided
Factor Cover Depth Fit Parameter B,	RN-specific	User Provided
Factor Cover Depth Fit Parameter KA, (cm^2/g)	RN-specific	User Provided
Factor Cover Depth Fit Parameter KB, (cm^2/g)	RN-specific	User Provided
Fractional Water Content in Game Meat,	0.78	User Provided
Fractional Water Content of Berries,	0.85	Fractional water content of berries, value for fruits. (IAEA te-1616)

(cont.) Constants		
Parameter	**Default**	**Information/Reference**
Fractional Water Content of Mushrooms,	0.9	User Provided
Fractional Water Content of the Crops,	Cereals 0.12 leafy vegetables 0.12 legumes 0.87 roots; 0.92	Fractional water content of the crops, (IAEA te-1616)
Fractional Water Content of the Garden Foods,	0.75	Fractional water content of the garden foods. (IAEA te-1616)
Ingestion rate of berries (kg.FW/year)	17	
Ingestion rate of berries by lactating mother, (kg.FW/year)	17	
Ingestion Rate of Breastmilk by Infant, (kg.FW/year)		Ingestion rate of breastmilk by infant.
Ingestion Rate of Crops, (kg.FW/year)		Crop types, Total annual crops consumption (kg-fresh weight/year), per crops types.
Ingestion Rate of Crops by Lactating Mother, (kg.FW/year)		Crop types, Total annual crops consumption (kg-fresh weight/year), per crops types.
Ingestion rate of freshwater food, (kg.FW/year)		Yearly consumption of different types of freshwater food
Ingestion rate of freshwater food by lactating mother, (kg.FW/year)		Yearly consumption of different types of freshwater food
Ingestion rate of game		
Ingestion rate of game by lactating mother		
Ingestion rate of garden food		
Ingestion rate of garden food by lactating mother		
Ingestion rate of marine food		Yearly consumption of different types of marine food
Ingestion rate of marine food by lactating mother, (kg.FW/year)	Fish: 0.262 Fish: 1.19 Mussels: 0.0	Yearly consumption of different types of marine food
Ingestion rate of meat	Adult: beef: 7.931 Adult, sheep: 0.208 Child, beef :10.865 Child, sheep: 0.285 Infant, beef: 7.5762 Infant, sheep: 0.198	

(cont.) Constants		
Parameter	**Default**	**Information/Reference**
Ingestion rate of meat by lactating mother, (kg.FW/year)	beef :7.9310 sheep:0.208	
Ingestion rate of milk, (L /year)	Adult, cow: 31.32 Child, cow :53.69 Infant, cow: 55.264	Yearly consumption of different types of milk
Ingestion rate of milk by lactating mother, (L /year)	31.320	Yearly consumption of different types of milk
Ingestion rate of mushrooms, (kg. FW/year)	Adult: 0.45 Child: 0.15 Infant: 4.8	(Turtiainen et al. 2015)
Ingestion rate of mushrooms by lactating mother, (kg.FW/year)	0.45	(Turtiainen et al. 2015)
Ingestion rate of soil, (kg.DW/h)	Default: 5.0E-6 Child: 1.0E-5 Infant: 5.0E-5	Ingestion rate of soil (kg-dry weight/h).
Ingestion rate of soil by lactating mother, (kgDW/h)	5.0E-6	Ingestion rate of soil (kg-dry weight/h). (Smith et al. 2004)
Ingestion rate of water (m^3/year)	Adult: 0.375 Child/Infant: 0.076	
Ingestion rate of water by lactating mother,(m^3/year)	0.375	(Amcoff et al. 2013)
Inhalation rate, (m^3/h)	Default 0.92 Infants 0.64	Inhalation rate (m3/h) (ICRP Publication 71).
Number of Seconds in A Year, (s/year)	3.1536E7	
Number of Seconds in One Hour,(s/h)	3600.0	
Precipitation Rate (m^3/(m^2*year))	0.674	
Reduction Factor for Calculation of Air Concentrations Indoors,	1	Ratio between indoor and outdoor air concentrations (values between zero and one)
Shielding factor of the building	1	Shielding factor against external exposure to outdoor radiation that is provided by the building
Transfer Factors from Ingested Activity to Breastmilk (d/kgFW)	1	Transfer factors from ingested activity to breastmilk
Transfer Factors from Inhaled Activity to Breastmilk, (d/kgFW)	1	From German regulations
Units Correction from DW to FW, (kgDW/kgFW)	1	Units correction from DW to FW
Water Content in Aquatic Food,	0.78	Values for fish, (IAEA te-161)
Water Content in Aquatic Food	0.78	Values for fish, (IAEA te-161)

Contaminated Soil Without Cover		
This module simulates contaminant "source term" for: - groundwater transport - Rn-222 exhalation to atmosphere, - external irradiation. The source of radiation is a layer of contaminated soil of a given thickness. There is no protective cover above the contaminated soil		
Parameter	**Default**	**Information/Reference**
Average Wind Speed (Annual),(m/s)	2	
Infiltration Recharge Rate, (m/year)	0.3	Infiltration recharge rate through waste layer
Mixing Height for Radionuclides Above the Source, (m)	2	Mixing height for radionuclides above the source
RN Concentration in Infiltration, (Bq/m^3)		Radionuclide Specific.
Specific Activity of RN in Waste (Initial), (Bq/kgDW)	10000.0	Initial specific waste activity of RN (time t=0)
Thickness of Waste Layer, (m)	3	
Waste Bulk Density, ($kgDW/m^3$)	1500	
Waste Kd, (m3/kgDW)	0.2	Waste sorption distribution coefficient Kd values, (IAEA, 2010)
Waste Moisture Content, (unitless)	0.15	
Waste Site Area (m^2)	4000	

Cover Layer		
Module to consider covers over the source that could be present in the assessed scenario.		
Parameter	**Default**	**Information/Reference**
Cover Thickness (m)	0.5	

Cropland		
Land where industrial agriculture is practiced		
Parameter	**Default**	**Information/Reference**
Area, (m^2)	30000	
Biomass of Crops, ($kgDW/m^2$)	cereals: 0.39 leafy vegetables: 0.54 legumes: 1.11 roots: 1.02	The aboveground biomass of crops in the considered cropland. The crops, and crop biomass, will depend on the crops that are grown in the considered crop land
Bioturbation, ($kgDW/(m^2*year)$	5.85	Amount of soil (per m^2 and year) that is affected by bioturbation, and the subsequent transport of radionuclides. Bioturbation is the physical rearrangement (reworking) of the upper part of the soil profile by soil life. Value is the average value of total bioturbation found in different soil types at Forsmark (15.9, 11.9, 0.99, 0.31, 0.19 kgdw/m2 y) in the study of Persson et al, 2007. (Löfgren A (ed), 2010)
Concentration of Dust in Atmospheric Air, (kg_{DW}/m^3)	5.0E-8	Löfgren A (ed), 2010)
Concentration of Radionuclides in Air Outdoors, (Bq/m^3)	RN-specific	User Provided
Concentration Ratio for Crops,	Crop types	The concentration ratio (radionuclide concentration in vegetation per radionuclide concentration in soil) for crops. Values are RN-specific and should as far as possible be vegetation type and environment specific.
Crop Exposure Period,	Crop types	The number of days that crops have above ground parts and as a result are exposed to radionuclides (e.g. through irrigation and deposition).
Density of The Deep Zone Soil, ($kgDW/m^3$)	2115	The dry bulk density of the deep zone soil in considered land object. The default value is for "other soils" (IAEA, 2001)
Density of The Rooting Zone Soil, ($kgDW/m^3$)	1626	The dry bulk density of the rooting zone soil in considered land object. The default value is for "peat soils" Typical density of the oxic top 0.25 m layer of a soil in Forsmark. (IAEA, 2001)
Deposition Rate, ($Bq\ year^{-1}\ m^{-2}$)		Radionuclide Specific, User Provided. The deposition rate of radionuclides on the surface of the considered object. Both dry and wet deposition should be considered
Distribution Coefficient for The Deep Soil Zone, ($m^3/kgDW$)		The distribution coefficients for the deep soil zone, i.e. for inorganic soils, of considered object. Values are element specific.
Distribution Coefficient for The Soil Rooting Zone, ($m^3/kgDW$)		The distribution coefficients for the rooting zone of the soil, i.e. for organic soils, of considered object. Values are element specific.
Erosion Rate, ($kgDW/(m^2*year)$)	0.05	The erosion rate of soils in the considered land type object. References: (Kirkby et al,2004)

(cont.) Cropland		
Parameter	**Default**	**Information/Reference**
Evapotranspiration Rate, (m^3/(m^2*year))		
Height of The Deep Soil Zone, (m)	0.5	Height (thickness) of the deep soil zone, i.e. the soil layer which extends from below the rooting zone to the groundwater table.
Height of The Soil Rooting Zone, (m)	0.25	Height (thickness) of the soil rooting zone. Assumed primary rooting depth of crops. Values agree with info on soil compartment "RegoUp_io" in table 2-1 in SKB, 2014. "Kd and CR for the Biosphere". Report R-13-01, which is used to describe the RZ_soil in this model (used e.g. for Kd, porosity and density). (Löfgren A (ed), 2010)
Initial Deposition On the Cropland, (Bq)	RN-specific	User Provided
Irrigation Rate for Crops, (m^3/ (m^2*year)		Crop types, the irrigation rate for crops in considered land type object. Default values are from Bioprota
Mass Interception Factor, (m^2/kgFW)	0.3	Mass interception factor for plants, defined as the fraction of deposited materials intercepted and initially retained (i.e. not immediately blown or washed off) by vegetation (unitless) divided by above ground biomass of vegetation per unit area (kg) (IAEA,2001)
Porosity of The Deep Soil Zone, (m^3/m^3)	0.21	Porosity of soil in the deep soil zone in the considered land use object. Typical porosity for till (which is the dominating soil type in the subcatchment) in Forsmark. (Table 2-1 in SKB, 2014. "Kd and CR for the Biosphere". Report R-13-01.)
Porosity of The Soil Rooting Zone, (m^3/m^3)	0.36	Porosity of the soil in the rooting zone of the considered land use object. Typical porosity for the oxic top 0.25 m layer of a soil in Forsmark.(Table 2-1 in SKB, 2014. "Kd and CR for the Biosphere". Report R-13-01)
RN Concentration in Irrigation Water,(Bq/m^3)	RN-specific	User Provided
Time Period of Irrigation of Crops, (day)		The number of days that vegetation is exposed to irrigation. (IAEA 2001)
Weathering Half Time (day)	22.4	Half time of removal of radionuclides from plant surfaces. Values presented are averages of presneted values in table 6 (over elements and plant groups). (IAEA,2010)

Forest		
Possible future improvements of this model: 1. Better consideration of interception by vegetation Consider effects of C-14 accumulation in soil, recycling to air and root uptake		
Parameter	**Default**	**Information/Reference**
Area, (m^2)	2000000	
Biomass of Leaves, ($kgDW/m^2$)	0.5	The biomass of tree leaves in the considered wetland. The biomass of the tree leaves will depend on the tree type considered (eg. deciduous or coniferous).
Biomass of Lichens, ($kgDW/m^2$)	0.5	
Biomass of Understorey, ($kgDW/m^2$)	0.08	The aboveground biomass of understorey plants
Biomass of Wood, ($kgDW/m^2$)	5.1	The biomass of tree wood in the considered wetland
Concentration of Dust in Atmospheric Air, ($kgDW/m^3$)	5.0E-8	Concentration of dust in atmospheric air, (Löfgren ed, 2010)
Concentration of Radionuclides in Air Outdoors, (Bq/m^3)	RN-specific	User Provided
Concentration Ratio for Berries, (kg_{DW}/kg_{DW})	RN-specific	The concentration ratio (radionuclide concentration in vegetation per radionuclide concentration in soil) for forest berries. Values are element specific and should as far as possible be vegetation type and environment specific.
Concentration Ratio for Game, (kg_{DW}/kg_{DW})	RN-specific	The concentration ratio (radionuclide concentration in animal per radionuclide concentration in animal feed) for game. Values are radionuclide specific and should as far as possible be animal and environment specific
Concentration Ratio for Mushrooms, (kg_{DW}/kg_{DW})	RN-specific	The concentration ratio (radionuclide concentration in mushrooms per radionuclide concentration in soil). Values are element specific and should as far as possible be environment specific.
Concentration Ratio for Tree Leaves, (kg_{DW}/kg_{DW})	RN-specific	The concentration ratio (radionuclide concentration in vegetation per radionuclide concentration in soil) for tree leaves. Values are element specific and should as far as possible be vegetation type and environment specific.
Concentration Ratio for Understorey, (kg_{DW}/kg_{DW})	RN-specific	The concentration ratio (radionuclide concentration in vegetation per radionuclide concentration in soil) for forest understorey vegetation. Values are element specific and should as far as possible be vegetation type and environment specific.
Concentration Ratio for Wood, (kg_{DW}/kg_{DW})	RN-specific	The concentration ratio (radionuclide concentration in vegetation per radionuclide concentration in soil) for tree wood. Values are element specific and should as far as possible be vegetation type and environment specific.

(cont.) Forest		
Parameter	**Default**	**Information/Reference**
Decomposition Rate, ($year^{-1}$)	0.9	The decomposition rate of litter (plant matter) in the considered object. Few samples from the site.User Provided
Density of The Deep Zone Soil, ($kgDW/m^3$)	2115	The dry bulk density of the deep zone soil in considered land object. (SKB, 2014. "Kd and CR for the Biosphere". Report R-13-01)
Density of The Rooting Zone Soil, ($kgDW/m^3$)	1626	The dry bulk density of the rooting zone soil in considered land object. (SKB, 2014. "Kd and CR for the Biosphere". Report R-13-01)
Deposition Rate, ($Bq\ year^{-1}\ m^{-2}$)	RN-specific	The deposition rate of radionuclides on the surface of the considered object. Both dry and wet deposition should be considered.
Distribution Coefficient for The Deep Soil Zone, (m^3/kg_{DW})	RN-specific	The distribution coefficients for the deep soil zone, i.e. for inorganic soils, of considered object.
Distribution Coefficient for The Soil Rooting Zone, (m^3/kg_{DW})	RN-specific	The distribution coefficients for the rooting zone of the soil, i.e. for organic soils, of considered object.
Fraction of Lichens Game, (unitless)	0.5	wild boar
Fraction of Leazes in Game Diet, (unitless)	30	moose, roe deer
Fraction of Mushrooms in Game Diet, (unitless)	10	moose, roe deer
Fraction of The Total Deposition Rate That Is Intercepted by Lichens, (unitless)	1	Radionuclide Specific. User Provided.
Fraction of Understorey in Game Diet, (unitless)	40	moose, roe deer
Fraction of Wood in Game Diet, (unitless)	20	moose, roe deer
Height of The Deep Soil Zone,(m)	0.5	Height (thickness) of the deep soil zone, i.e. the soil layer which extends from below the rooting zone to the groundwater table.
Height of The Soil Rooting Zone, (m)	0.25 m	Height (thickness) of the soil-rooting zone. (Löfgren A (ed), 2010)
Initial Deposition On the Forest, (Bq)		Radionuclide Specific. User Provided.
Net Primary Production of Tree Leaves, ($kgDW/(m^2*$ year))	0.08	The net primary production of tree leaves in forest.
Net Primary Production of Understorey, ($kgDW/(m^2*$ year))	0.08	The net primary production of understorey in forest.
Net Primary Production of Wood, ($kgDW/(m^2*$ year))	0.18	The net primary production of wood in forest.

(cont.) Forest		
Parameter	**Default**	**Information/Reference**
Porosity of The Deep Soil Zone, (m^3/m^3)	0.21	Porosity of soil in the deep soil zone in the considered land use object. (Table 2-1 in SKB, 2014. "Kd and CR for the Biosphere". Report R-13-01)
Porosity of The Soil Rooting Zone, (m^3/m^3)	0.36	Porosity of the soil in the rooting zone of the considered land use object. (Table 2-1 in SKB, 2014. "Kd and CR for the Biosphere". Report R-13-01)
Rain Interception Factor,	0.3	Fraction of the rain that is intercepted by the vegetation
Rate of Leaching Of Radionuclides From Lichens, ($year^{-1}$)	0.2	Radionuclide Specific. User Provided.
Transpiration Rate [$m^3/(m^2*year)$]	0.335	

Fresh Water Body		
Module simulates radionuclide (RN) transport and fate in lake water (sediments). This module takes into account the following process: - RN inflow to lake with water (surface water / groundwater) - RN releases to lake due to different process (atmospheric deposition, discharges etc.) - RN decay - RN removal from water column due to sedimentation of suspended particles - RN outflow from the lake with water (surface water / groundwater)		
Parameter	**Default**	**Information/Reference**
Average Lake Depth, (m)	5.58	SMHI website
Bulk Density of Soil in Subcathmnent Area, (kgDW/m^3)	2115	Table 2-1 in SKB, 2014. "Kd and CR for the Biosphere". Report R-13-01.
Concentration of Suspended Particulate Matter in Lake Water, (kgDW/m^3)	0.007	(POSIVA BSA, 2012)
Concentration Ratio for Freshwater Food, (m3/kgDW)	RN-specific	The concentration ratio (radionuclide concentration in aquatic food per element concentration in water) for freshwater food (Fish, cray fish, mussels). Values are element specific and should, as far as possible, be food type and environment specific.
Density of The Deep Sediment Layer, (kgDW/m^3)	71.7	The dry bulk density of the deep sediment layer.
Density of The Top Sediment Layer, (kgDW/m^3)	179	The dry bulk density of the top sediment layer. This is considered the bioturbated layer of the sediment. (SKB, 2014. "Kd and CR for the Biosphere". Report R-13-01. See table 2-1 of the report.)
Deposition Rate, (Bq/(m^2*year))	RN-specific	Radionuclide Specific.
Deposition Rate Over the Lake Subcatchment, (Bq/(m^2*year))	RN-specific	Total deposition rate, dry and wet, of radionuclides over the lake subcatchment
Distribution Coefficient for Suspended Particulate Matter, (m^3/kg_{DW})		The distribution coefficients for the suspended particulate matter in the lake. Values are element specific.
Distribution Coefficient of Soil in The Lake Subcatchment Area, (m^3/kg_{DW})		Distribution coefficient of soil in the lake subcatchment area.
Height of The Deep Sediment Layer, (m)	0.96	Height (thickness) of the deep sediment layer of the lake.
Height of The Top Sediment Layer, (m)	0.05	Height (thickness) of the top sediment layer of the lake. This is considered the bioturbated layer of the sediment. It is thickness is kept constant in time. (SKB, 2014. "Kd and CR for the Biosphere". Report R-13-01. See table 2-1 of the report, and chapter 5.10)
Initial Deposition On the Subcathment, (Bq)		Deposition on subcathment compartment of the freshwater body
Initial Deposition On Water, (Bq)		On the water compartment of the freshwater body

(cont.) Fresh Water Body		
Parameter	**Default**	**Information/Reference**
Lake Area, (m)	1800000	
Measured Radionuclide Concentration in Water,		
Porosity of Soil in Subcathment Area, (m^3/m^3)	0.21	water filled porosity of soil in subcathment area. (Table 2-1 in SKB, 2014. "Kd and CR for the Biosphere", Report R-13-01)
Porosity of The Top Sediment, (m^3/m^3)	0.92	Porosity of the soil in the top sediment in lake. This is considered the bioturbated layer of the sediment. (SKB, 2014. "Kd and CR for the Biosphere", Report R-13-01. See table 2-1 of the report)
Radionuclide Distribution Coefficient, (m^3/kgDW)		The distribution coefficients for the top layer of the lake bottom sediment. Values are element specific.
Release Rate of Radionuclides, (Bq/year)	RN-specific	User Provided.
Resuspension Rate, (kgDW/(m^2*year)		The sediment resuspension (the renewed suspension of a precipitated sediment) rate in lake.
Runoff, (m/year)	0.2	The runoff (P-ET, assuming no change in storage and a closed system) in the considered area
Sedimentation Rate, (kgDW/(m^2*year))	0.05	The sedimentation rate of particles in the lake water, i.e. the rate at which particles in suspension settle out of the water and come to rest on the lake bottom.
Subcatchment Area, (m^2)	1.5E7	Area of the lake subcatchment
Thickness of Soil in Subcathment Area, (m)	0.5	
Upstream Water Flux (m^3/year)	0	Water flux from affluent river or other water body upstream

Garden Plot		
Parameter	**Default**	**Information/Reference**
Area, (m^2)	9	
Biomass of Garden Foods, (kg_{DW}/m^2)	Default: 0.0 Fruits: 0.39 Leafy vegetables:1.11 Roots: 1.02	The aboveground biomass of garden foods in the considered garden plot. Types of edible vegetation grown in the garden plot
Bioturbation, ($kg_{DW}/(m^2*year)$)	5.858	Amount of soil (per m^2 and year) that is affected by biturbation, and the subsequent transport of radionuclides. Bioturbation is the physical rearrangement (reworking) of the upper part of the soil profile by soil life (Löfgren A (ed), 2010)
Concentration of Dust in Atmospheric Air, ($kgDW/m^3$)	5.0E-8	Concentration of dust in atmospheric air.
Concentration of Radionuclides in Air Outdoors, (Bq/m^3)	RN-specific	User Provided.
Concentration Ratio for Garden Foods, (kg_{DW}/kg_{DW})	RN-specific	The concentration ratio (radionuclide concentration in vegetation per radionuclide concentration in soil) for garden foods. Values are element specific and should as far as possible be vegetation type and environment specific.
Density of The Deep Zone Soil, (kg_{DW}/m^3)	2115	The dry bulk density of the deep zone soil in considered land object.Table 2-1 in SKB, 2014. "Kd and CR for the Biosphere". Report R-13-01.
Density of The Rooting Zone Soil, (kg_{DW}/m^3)	1626	The dry bulk density of the rooting zone soil in considered land object. Table 2-1 in SKB, 2014. "Kd and CR for the Biosphere". Report R-13-01.
Deposition Rate, ($Bq\ year^{-1}\ m^{-2}$)	RN-specific	The deposition rate of radionuclides on the surface of the considered object. Both dry and wet deposition should be considered.
Distribution Coefficient for The Deep Soil Zone, (m^3/kg_{DW})	RN-specific	The distribution coefficients for the deep soil zone, i.e. for inorganic soils, of considered object. Values are element specific.
Distribution Coefficient for The Soil Rooting Zone, (m^3/kg_{DW})	RN-specific	The distribution coefficients for the rooting zone of the soil, i.e. for organic soils, of considered object.
Erosion Rate, ($kgDW/(m^2*year)$)	0.05	The erosion rate of soils in the considered land type object. (Kirkby et al, 2004)
Evapotranspiration Rate, ($m^3/(m^2*year)$)		Types of edible vegetation grown in the garden plot

(cont.) Garden Plot		
Parameter	**Default**	**Information/Reference**
Garden Crops Exposure Period, (days)	75	The number of days that garden foods have above ground parts and as a result are exposed to radionuclides (e.g. through irrigation and deposition).
Height of The Deep Soil Zone, (m)	0.5	Height (thickness) of the deep soil zone, i.e. the soil layer which extends from below the rooting zone to the groundwater table.
Height of The Soil Rooting Zone, (m)	0.25	(Löfgren A (ed), 2010)
Initial Deposition On the Forest, (Bq)		
Irrigation Rate for Garden Foods, ($m^3/(m^2*year)$)		The irrigation rate for garden food in considered garden plot
Mass Interception Factor, ($m^2/kgFW$)	0.3	Mass interception factor for plants, defined as the fraction of deposited materials intercepted and initially retained (i.e. not immediately blown or washed off) by vegetation (unitless) divided by above ground biomass of vegetation per unit area (kg) (IAEA,2001)
Porosity of The Deep Soil Zone, (m^3/m^3)	0.21	Porosity of soil in the deep soil zone in the considered land use object. (Table 2-1 in SKB, 2014. "Kd and CR for the Biosphere". Report R-13-01)
Porosity of The Soil Rooting Zone, (m^3/m^3)	0.36	Porosity of the soil in the rooting zone of the considered land use object. (Table 2-1 in SKB, 2014. "Kd and CR for the Biosphere". Report R-13-01)
RN Concentration in Irrigation Water, (Bq/m^3)	RN-specific	User Provided
Time Period of Irrigation of Garden Foods,		The number of days that vegetation is exposed to irrigation. (IAEA,2001)
Weathering Half Time (day)	22.4	Half time of removal of radionuclides from plant surfaces.

House		
This is used for assessment of indoor air concentrations		
Parameter	**Default**	**Information/Reference**
Area of The House, (m^2)	100	
Exchange of Air in The House, (h^{-1})	0.5	
Radon Concentrations in Air Outdoors, (Bq/m^3)		
Radon Flux Density into The House from The Foundament, ($Bq/(m^2*s)$)		
RN Concentration in Outdoor Air, (Bq/m^3)		The measured radionuclides concentrations in air outside building.
Volume of The House (m^3)	500	

House Slab		
Module to consider attenuation of Radon fluxes and gamma dose rates by a house slab, i.e. by the house foundation.		
Parameter	**Default**	**Information/Reference**
Cover Thickness (m)	0.5	

Land		
Parameter	**Default**	**Information/Reference**
Area, (m^2)	20000	
Bioturbation, (kg_{DW}/ (m^2*year)	5.858	Amount of soil (per m^2 and year) that is affected by biturbation, and the subsequent transport of radionuclides. Bioturbation is the physical rearrangement (reworking) of the upper part of the soil profile by soil life. (Löfgren A (ed), 2010)
Concentration of Dust in Atmospheric Air, ($kgDW/m^3$)	5.0E-8	Concentration of dust in atmospheric air. (Löfgren A (ed), 2010)
Concentration of Radionuclides in Air Outdoors, (Bq/m^3)	RN-specific	User Provided
Density of The Deep Zone Soil, (kg_{DW}/m^3)	2115	The dry bulk density of the deep zone soil in considered land object. (SKB, 2014. "Kd and CR for the Biosphere". Report R-13-01)
Density of The Rooting Zone Soil, (kg_{DW}/m^3)	1626	The dry bulk density of the rooting zone soil in considered land object.(SKB, 2014. "Kd and CR for the Biosphere". Report R-13-01.)
Deposition Rate, (Bq $year^{-1}$ m^{-2})		The deposition rate of radionuclides on the surface of the considered object. Both dry and wet deposition should be considered.
Distribution Coefficient for The Deep Soil Zone, (m^3/kg_{DW})	RN-specific	The distribution coefficients for the deep soil zone, i.e. for inorganic soils, of considered object.
Distribution Coefficient for The Soil Rooting Zone, (m^3/kg_{DW})	RN-specific	The distribution coefficients for the rooting zone of the soil, i.e. for organic soils, of considered object.
Erosion Rate, ($kgDW/(m^2$*year))	0.05	The erosion rate of soils in the considered land type object. (Kirkby et al,2004)
Evapotranspiration Rate, ($m^3/(m^2$*year))		Types of edible vegetation grown in the garden plot
Height of The Deep Soil Zone, (m)	0.5	Height (thickness) of the deep soil zone, i.e. the soil layer which extends from below the rooting zone to the groundwater table.
Height of The Soil Rooting Zone, (m)	0.25	Height (thickness) of the soil rooting zone. (Löfgren A (ed), 2010)
Initial Depostion On the Forest, (Bq)		
Measured Radionuclide Concentration in Soil, (m)	0.25	
Porosity of The Deep Soil Zone, (m^3/m^3)	0.21	Porosity of soil in the deep soil zone in the considered land use object. (Table 2-1 in SKB, 2014. "Kd and CR for the Biosphere". Report R-13-01)
Porosity of The Soil Rooting Zone (m^3/m^3)	0.36	Porosity of the soil in the rooting zone of the considered land use object. (Table 2-1 in SKB, 2014. "Kd and CR for the Biosphere". Report R-13-01)

Marine		
Parameter	**Default**	**Information/Reference**
Accumulation Time in Beach Sediment, (years)	50	
Area, (m^2)	12345.0	User Provided
Bioturbation Coefficient, (m^2/year)	1	
Bulk Density of The Beach Sediment, ($kgDW/m^3$)	1200	
Characteristic Lenght of The Middle Sediment Layer (m)	1	
Characteristic Lenght of the Top Sediment Layer, (m)	1	
Concentration of Suspended Particulate Matter in Lake Water, ($kgDW/m^3$)	1	
Concentration Ratio for Marine Food, (m^3/kgDW)	RN-specific	The concentration ratio (radionuclide concentration in marine food per element concentration in water) for marine food. Values are element specific and should, as far as possible, be food type and environment specific.
Density of Sediment Particles, ($kgDW/m^3$)	1	
Deposition Rate, (Bq $year^{-1}$ m^{-2})		The deposition rate of radionuclides on the surface of the considered object. Both dry and wet deposition should be considered.
Depth of Water Box, (m)	1	
Distribution Coefficient for Suspended Particulate Matter, (m^3/kg_{DW})	RN-specific	The distribution coefficients for the suspended particulate matter in the lake.
Flux in Par, (Bq/year)	RN-specific	User Provided
Initial Deposition On the Water of Marine Box, (Bq)		
Measured Radionuclide Concentration in Water,		
Physical Diffusivity Coefficient, (m^2/year)	1	
Porosity,	0.5	
Radionuclide Distribution Coefficient, (m^3/kgDW)	RN-specific	User Provided
Release Rate of Radionuclides, (Bq/year)	RN-specific	User Provided
Sedimentation Velocity of Solid Particles, (m/year)	1	is the velocity of solid particles settling down in gravity field
Thickness of The Top Layer of the Beach Sediment, (m)	0.05	
Volume (m^3)	61.68	

Pasture Land		
Losses from the system by pasture are conservatively neglected. This may give a substantial overestimation for radionuclides with high Kds. Consider this effect in supporting simulations.		
Parameter	**Default**	**Information/Reference**
Area, (m^2)	20000	
Biomass of Pasture, (kg_{DW}/m^2)	0.33	The aboveground biomass of pasture in the considered pasture land. (POSIVA BSA-2012)
Bioturbation, ($kg_{DW}/(m^2*year)$)	5.858	Amount of soil (per m^2 and year) that is affected by biturbation, and the subsequent transport of radionuclides. Bioturbation is the physical rearrangement (reworking) of the upper part of the soil profile by soil life. (Löfgren A (ed), 2010)
Concentration of Dust in Atmospheric Air, ($kgDW/m^3$)	5.0E-8	Concentration of dust in atmospheric air. (Löfgren A (ed), 2010)
Concentration of Radionuclides in Air Outdoors, (Bq/m^3)	RN-specific	
Concentration Ratio for Pasture, (kg_{DW}/kg_{DW})	RN-specific	The concentration ratio (radionuclide concentration in vegetation per radionuclide concentration in soil) for garden foods. Values are element specific and should as far as possible be vegetation type and environment specific.
Density of The Deep Zone Soil, (kg_{DW}/m^3)	2115	The dry bulk density of the deep zone soil in considered land object. (SKB, 2014. "Kd and CR for the Biosphere". Report R-13-01)
Density of The Rooting Zone Soil, (kg_{DW}/m^3)	1626	The dry bulk density of the rooting zone soil in considered land object. (SKB, 2014. "Kd and CR for the Biosphere". Report R-13-01).
Deposition Rate, ($Bq\ year^{-1}\ m^{-2}$)	RN-specific	The deposition rate of radionuclides on the surface of the considered object. Both dry and wet deposition should be considered.
Distribution Coefficient for The Deep Soil Zone, (m^3/kg_{DW})	RN-specific	The distribution coefficients for the deep soil zone, i.e. for inorganic soils, of considered object.
Distribution Coefficient for The Soil Rooting Zone, (m^3/kg_{DW})	RN-specific	The distribution coefficients for the rooting zone of the soil, i.e. for organic soils, of considered object.
Erosion Rate, ($kgDW/(m^2*year)$)	0.05	The erosion rate of soils in the considered land type object. (Kirkby et al,2004)
Evapotranspiration Rate, ($m3/(m^2*year)$)		Types of edible vegetation grown in the garden plot
Fraction of Year During Which Meat Animals Are Grazing Pasture,	0.25	The fraction of the year during which meat producing animals are grazing the pasture. (SJVFS 2010:15)
Height of The Deep Soil Zone, (m)	0.5	Height (thickness) of the deep soil zone, i.e. the soil layer which extends from below the rooting zone to the groundwater table.
Height of The Soil Rooting Zone, (m)	0.25	(Löfgren A (ed), 2010).
Ingestion Rate of Pasture by Meat Animals, (kgDW/day)	Beef: 11.44	The ingestion rates of pasture by meat producing animals. Values are animal type specific.

(cont.) Pasture Land		
Parameter	**Default**	**Information/Reference**
Ingestion Rate of Pasture by Milk Animals, (kgDW/day)	Cow: 9.1	The ingestion rates of pasture by meat producing animals. Values are animal type specific.
Ingestion Rate of Soil by Meat Animals, (kgDW/day)	Beef: 0.7	The ingestion rates of soil by meat producing animals. Values are animal type specific
Ingestion Rate of Soil by Milk Animals, (kgDW/day)	Cow: 0.6	The ingestion rates of soil by milk producing animals. Values are animal type specific.
Ingestion Rate of Water by Meat Animals, (m^3/day)	Beef: 0.06	The ingestion rates of soil by meat producing animals. Values are animal type specific
Ingestion Rate of Water by Milk Animals, (m^3/day)	Cow: 0.04	The ingestion rates of soil by milk producing animals. Values are animal type specific
Initial Deposition On the Forest, (Bq)	RN-specific	Radionuclide Specific. User Provided.
Irrigation Rate for Pasture, (m^3/(m^2*year))		The irrigation rate for pasture in considered land type object. (Brundell et al. 2008 + SCB 2012 + Jordbruksverket 2009)
Mass Interception Factor, (m2/kgDW)	3	Mass interception factor for plants, defined as the fraction of deposited materials intercepted and initially retained (i.e. not immediately blown or washed off) by vegetation (unitless) divided by above ground biomass of vegetation per unit area (kg) (IAEA,2001)
Pasture Exposure Period, (day)	30	The number of days that vegetation is exposed to processes which will affect the radionuclide concentration in the vegetation. The vegetation exposure period equals the vegetation growth period. (IAEA, 2001).
Porosity of The Deep Soil Zone, (m^3/m^3)	0.21	Porosity of soil in the deep soil zone in the considered land use object. (Table 2-1 in SKB, 2014. "Kd and CR for the Biosphere". Report R-13-01)
Porosity of The Soil Rooting Zone, (m^3/m^3)	0.36	Porosity of the soil in the rooting zone of the considered land use object. (Table 2-1 in SKB, 2014. "Kd and CR for the Biosphere". Report R-13-01)
RN Concentration in Animals Drinking Water, (Bq/m^3)	RN-specific	User Provided. RN concentration in meat, RN concentration in milk
RN Concentration in Irrigation Water, (Bq/m^3)	RN-specific	Irrigation, RN concentration in crops by interception from air.
Time Period of Irrigation of Pasture, (day)	7.5	The number of days that vegetation is exposed to irrigation. (IAEA, 2001)
Transfer Factor to Meat, (day/kg_{FW})	Animal specific	The transfer factor relating the uptake of elements in muscle tissue (meat) of an animal to the intake of food, water and soil by the meat animal.
Transfer Factor to Milk, (day/L)	Animal specific	The transfer factor relating the concentration of radionuclides in milk to the intake of food, water and soil by the animal.
Weathering Half Time, (day)	22.4	half time of removal of radionuclides from plant surfaces. (IAEA, 2010)

Surface Runoff		
Module simulates radionuclide (RN) run-off from watershed soil in dissolved form This module takes into account the following process: - RN transport by surface runoff in dissolved form - RN transport by surface runoff sorbed on suspended particles - RN leaching to deeper layers - RN deposition from atmosphere. It is assumed that RN interaction between water and soil occurs in “exchangeable soil layer”. All radionuclide inventories in exchangeable layer is in ion-exchangeable form.		
Parameter	**Default**	**Information/Reference**
Area of The Watershed, (m^2)	10000	User Provided
Atmospheric RN Deposition Rate, (Bq/ (m^2 year))	RN-specific	User Provided
Concentration of Suspended Soil Particles I in Runoff Water, (g/m^3)	20	
Flux Runoff Upstream, (Bq $year^{-1}$)	RN-specific	User Provided
Infiltration Coefficient, (unitless)	0.3	Infiltration coefficient: fraction of precipitation that infiltrates to soil profile
Kd for Suspended Particles, (m^3/kg_{DW})	100	Kd for suspended particles in surface runoff
Precipitation Rate, (m/year)	0.6	Precipitation rate (rainfall)
Radionuclide Concentration in Watershed Soil (Initial Value), (Bq/kgDW)		Radionuclide concentration in watershed soil in exchangeable layer (initial value).
Soil Density, ($kgDW/m^3$)	1650	
Soil Kd, (m^3/kg_{DW})	RN-specific	User Provided, Kd for watershed soil
Soil Moisture Content, (unitless)	0.1	Watershed soil moisture content (in exchangeable layer)
Surface Runoff Coefficient, (unitless)	0.1	Surface runoff coefficient for the watershed (portion of precipitation which turns to surface runoff)
Thickness of Soil (Exchangeable Layer) (m)	0.02	Thickness of watershed soil (exchangeable layer)

Tailing Without Cover		
This module simulates contaminant "source term" for: - groundwater transport - Rn-222 exhalation to atmosphere, - external irradiation. The source of radiation is a layer of contaminated waste of a given thickness. There is no protective cover above the contaminated waste layer		
Parameter	**Default**	**Information/Reference**
Average Wind Speed (Annual), (m/s)	2	User Provided
Infiltration Recharge Rate, (m/year)	0.3	Infiltration recharge rate through waste layer
Mixing Height for Radionuclides Above the Source, (m)	2	
RN Concentration in Infiltration, (Bq/m^3)	RN-specific	
Specific Activity of RN in Waste (Initial), (Bq/kgDW)	10000	Initial specific waste activity of RN (time t=0)
Thickness of Waste Layer,	3 m	
Waste Bulk Density, ($kgDW/m^3$)	1500	
Waste Kd, (m^3/kgDW)	0.2	Waste sorption distribution coefficient Kd values Reference: (IAEA, 2010)
Waste Moisture Content, (unitless)	0.15	Contaminated soil (waste) moisture content
Waste Site Area (m^2)	4000	Waste site (contaminated soil) area

Total Dose		
Total dose to different population groups by all exposure pathways taking into account contributions from all objects and radionuclides.		
Parameter	**Default**	**Information/Reference**
Total Dose from External Exposure Summed Over All Radionuclides, (Sv/year)		Annual effective dose to different exposed groups
Total Dose from Ingestion of Food Summed Over All Radionuclides, (Sv/year)		Annual effective dose to different exposed groups
Total Dose from Ingestion of Water Summed Over All Radionuclides, (Sv/year)		Annual effective dose to different exposed groups
Total Dose from Inhalation Summed Over All Radionuclides, (Sv/year)		Annual effective dose to different exposed groups
Total Dose from Soil Ingestion Summed Over All Radionuclides, (Sv/year)		Annual effective dose to different exposed groups

Unsaturated Zone

This module simulates radionuclide transport in the unsaturated zone accounting for advection, dispersion, radioactive decay and sorption “Transport" block is used to simulate radionuclide migration The number of compartments N in transport block is determined automatically considering the accuracy of approximation of the advection-dispersion terms. (Parameter "dispersion accuracy" is used to control the accuracy of numerical approximations of advection-dispersion. The smaller is this parameter the larger is the number of compartments. The recommended value is 0.1-0.2).

Parameter	Default	Information/Reference
Dispersion Accuracy, (unitless)	0.2	Parameter controlling accuracy of approximation of dispersion flux in Transport_UZ block, (recommended value 0.1-0.2)
Infiltration Recharge Rate, (m/year)	0.05	Infiltration recharge rate through the unsaturated zone
Initial Specific Activity of Soil,(Bq/kgDW)		Initial specific activity of soil in the unsaturated zone (at time t=0)
Moisture Content in The UZ, (unitless)	0.15	
N Max, (unitless)	100	Maximum number of blocks in Transport_UZ block
N Min, (unitless)	5	Minimum number of cells in Transport_UZ block
RN Concentration in Infiltration, (Bq/m^3)	RN-specific	Radionuclides (RN) concentration in infiltration recharge water. User Provided
Soil Bulk Density in UZ, ($kgDW/m^3$)	2000	
Thickness of The UZ, (m)	8	Thickness of the unsaturated zone
Unsaturated Zone Kd, ($m^3/kgDW$)	0.7	Unsaturated zone sorption Kd values
Waste Site Area (m^2)	42000	Waste site (contaminated soil) area

Well

This module calculates radionuclide concentrations in groundwater pumped by a water well. It is assumed that some fraction of the well debit is formed by contaminated groundwater from the flow tube originating from the waste site, while the other part of well debit is formed by "background" groundwater

Parameter	Default	Information/Reference
Fraction of Groundwater Coming to The Well from The Flow Tube, (unitless)	1	The fraction of groundwater coming to the well from the flow tube.
RN Concentration in Background Groundwater, (Bq/m^3)	RN-specific	User Provided, The radionuclide concentration in the background groundwater
RN Concentration in The Water Coming from The Aquifer (Bq/m^3)		The radionuclide concentration in the aquifer (flow tube) groundwater flowing into the well

Cover Layer, Dose rate		
Parameter	**Default**	**Information/Reference**
Cover Density, (kgDW/m^3)	1300	
Effective Dose Rate Before Attenuation by The Cover, (Sv/h)	RN-specific	User Provided
Input Product Density Cover Times Cover Thickness, (kgDW*m/m^3)		Input product density cover times cover thickness.
Previous Cumulative Thickness, (m)		Previous cumulative thickness.
Source Layer Density, (kgDW/m^3)		
Thickness of The Source (m)	0.5	

House Slab. Dose rate		
Parameter	**Default**	**Information/Reference**
Cover Density, (kgDW/m^3)	1300	
Effective Dose Rate Before Attenuation by The Cover, (Sv/h)	RN-specific	
Input Product Density Cover Times Cover Thickness, (kgDW*m/m^3)		Input product density cover times cover thickness.
Previous Cumulative Thickness, (m)		Previous cumulative thickness.
Source Layer Density, (kgDW/m^3)		
Thickness of The Source (m)	0.5	

Radon, Tailing Without Cover		
Parameter	**Default**	**Information/Reference**
Diffusion Coefficient for Rn (Tailings Matrix), (m^2/s)	1.3E-6	Diffusion coefficient for Rn (tailings matrix)
Rn Emanation Coefficient (unitless)	0.2	Rn emanation coefficient

Cover Layer. Radon		
Parameter	**Default**	**Information/Reference**
Average Wind Speed (Annual), (m/s)	2	
Incoming Radon Flux, (Bq/(m^2*s))		Radon flux incoming from the previous layer
Layer Diffusion Coefficient for Rn, (m^2/s)	7.8E-7	Radon diffusion coefficient for the cover.
Mixing Height for Rn Above the Source, (m)	2	Mixing height for Rn above the source
Site Area (m^2)		Area of tailings site, Radionuclide release rate to atmosphere, Radon concentration in air

Contaminated Soil Without Cover, Radon		
Parameter	**Default**	**Information/Reference**
Diffusion Coefficient for Rn (Tailings Matrix), (m^2/s)	1.3E-6	Diffusion coefficient for Rn (tailings matrix)
Rn Emanation Coefficient (unitless)	0.2	Rn emanation coefficient

House Slab, Radon		
Parameter	**Default**	**Information/Reference**
Incoming Radon Flux, (Bq/(m^2*s))		Radon flux incoming from the previous layer
Layer Diffusion Coefficient for Rn (m^2/s)	7.8E-7	Radon diffusion coefficient for the cover

4.3 NORMALYSA References:

IAEA, 2010. Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments. IAEA Technical Report Series 472. International Atomic Agency, Vienna, Austria. http://www-pub.iaea.org/MTCD/publications/PDF/trs472_web.pdf

IAEA, E., Fesenko, S., Voigt, G., & Linsley, G. (2009). *Quantification of Radionuclide Transfer in Terrestrial and Freshwater Environments for Radiological Assessments*. International Atomic Energy Agency, Vienna, Austria. http://www-pub.iaea.org/MTCD/publications/PDF/te_1616_web.pdf

IAEA, (2001*). Generic models for use in assessing the impact of discharges of radioactive substances to the environment*. IAEA Safety Reports Series No. 19. International Atomic Energy Agency, Vienna, Austria. http://www-pub.iaea.org/MTCD/publications/PDF/Pub1103_scr.pdf

Department Radiation Protection and Environment Salzgitter (BfS), (2011), *Calculation Guide Mining; Calculation Guide for the Determination of Radiation Exposure due to Environmental Radioactivity Resulting from Mining Department Radiation Protection and Environment*. Germany.

SKB, (2014). Kd and CR used for transport calculations in the biosphere in SR-PSU, Report R-13-01. Stockholm, Sweden

Löfgren A (ed), (2010). The terrestrial ecosystems at Forsmark and Laxemar-Simpevarp. SR-Site Biosphere. SKB TR-10-01, Svensk Kärnbränslehantering AB, and Persson T, Lenoir L, Taylor A, 2007. Bioturbation in different ecosystems at Forsmark and Oskarshamn. SKB R-06-123, Svensk Kärnbränslehantering AB.

Kirkby, M.J., Jones, R.J.A., Irvine, B., Gobin, A, Govers, G., Cerdan, O., Van Rompaey, A.J.J., Le Bissonnais, Y., Daroussin, J., King, D., Montanarella, L., Grimm, M., Vieillefont, V., Puigdefabregas, J., Boer, M., Kosmas, C., Yassoglou, N., Tsara, M., Mantel, S., Van Lynden, G.J., & Huting, J. (2004). Pan-European Soil Erosion Risk Assessment: The PESERA Map,

Version 1 October 2003. EUR 21176. Luxembourg: Office for Official Publications of the European Communities.

POSIVA BSA-(2012), *Safety Case for the Disposal of Spent Nuclear Fuel at Olkiluoto - Data Basis for the Biosphere Assessment BSA-2012*, EURAJOKI, FINLAND. http://www.posiva.fi/en/databank/posiva_reports/safety_case_for_the_disposal_of_spent_nuclear_fuel_at_olkiluoto_-_data_basis_for_the_biosphere_assessment_bsa-2012.1871.xhtml?xm_col_type=4&cd_offset=30#.WblMt-vytpg

ICRP (1995). Age-dependent Doses to Members of the Public from Intake of Radionuclides - Part 4 Inhalation Dose Coefficients. ICRP Publication 71. Ann. ICRP 25 (3-4).

Turtiainen, M., (2015). Modelling bilberry and cowberry yields in Finland: different approaches to develop models for forest planning calculations. Dissertationes Forestales 185, 56.

V. The Radioactively Contaminated Land Exposure Assessment Methodology (RCLEA)

The Radioactively Contaminated Land Exposure Assessment Methodology (RCLEA) is a mathematical model developed by Quintessa in support of the U.K. Government Department for Environment, Food and Rural Affairs (DEFRA) Part IIA for managing contaminated land in the UK. RCLEA is an Excel file with a collection of worksheets that contain all input data and results

The default input data is protected against any change, and the equations are hidden. The model can be used for generic and site-specific calculations. RCLEA has four options to build a scenario: 1) land use scenarios, 2) building type (timber framed or brick); 3) age of the exposed individual (adult, infant or child), and 4) sex of the exposed individual (male or female). RCLEA was issued in 2003 and may be downloaded at: http://www.rclea.info/index.htm.

5.1 RCLEA Exposure Scenarios and Pathways

RCLEA contains four scenarios: Residential with Home-Grown Produce, Residential without Home-Grown Produce, Allotments, and Commercial/Industrial. It can calculate doses from whole body external irradiation, ingestion, dermal contact, inhalation, consumption of homegrown produce, and inhalation of Rn-222 gas indoors.

5.2 RCLEA Recommended Default Input Parameters

Element Dependent Data

	Soil to Liquid Distribution Coefficient for Soil		Plant uptake affinity		Soil-to-Plant Concentration Factor			
	(m³/kg)		(-)		(Bq/kg(fw) per Bq/kg(dw))			
Element	Library	User	Library	User	Library	User	Formula	Value
Ac	1	1	0.5	0.5	4.00E-04	4.00E-04	4.00E-04	4.00E-04
Ag	0.1	0.1	5	5	4.00E-02	4.00E-02	4.00E-02	4.00E-02
Am	5	5	0.5	0.5	7.00E-05	7.00E-05	7.00E-05	7.00E-05
C	0.02	0.02	5	5	2.00E-01	2.00E-01	2.00E-01	2.00E-01
Co	0.5	0.5	5	5	7.00E-03	7.00E-03	7.00E-03	7.00E-03
Cs	1	1	5	5	4.00E-03	4.00E-03	4.00E-03	4.00E-03
Eu	0.8	0.8	0.5	0.5	4.00E-04	4.00E-04	4.00E-04	4.00E-04
Fe	0.5	0.5	5	5	7.00E-03	7.00E-03	7.00E-03	7.00E-03
H	0	0	0	0	6.00E+00	6.00E+00	6.00E+00	6.00E+00
I	0.02	0.02	0.1	0.1	4.00E-03	4.00E-03	4.00E-03	4.00E-03
K	0.2	0.2	50	50	2.00E-01	2.00E-01	2.00E-01	2.00E-01
Mo	0.05	0.05	5	5	7.00E-02	7.00E-02	7.00E-02	7.00E-02
Nb	0.5	0.5	0.5	0.5	4.00E-04	4.00E-04	7.00E-04	7.00E-04
Ni	0.5	0.5	5	5	7.00E-03	7.00E-03	7.00E-03	7.00E-03
Np	0.03	0.03	0.5	0.5	1.00E-02	1.00E-02	1.00E-02	1.00E-02
Pa	1	1	0.5	0.5	4.00E-04	4.00E-04	4.00E-04	4.00E-04
Pb	1	1	5	5	4.00E-03	4.00E-03	4.00E-03	4.00E-03
Pm	0.8	0.8	0.5	0.5	4.00E-04	4.00E-04	4.00E-04	4.00E-04
Pu	1	1	0.5	0.5	4.00E-04	4.00E-04	4.00E-04	4.00E-04
Ra	5	5	5	5	7.00E-04	7.00E-04	7.00E-04	7.00E-04
Sb	0.1	0.1	5	5	4.00E-02	4.00E-02	4.00E-02	4.00E-02
Se	0.05	0.05	50	50	7.00E-01	7.00E-01	7.00E-01	7.00E-01
Sm	0.8	0.8	0.5	0.5	4.00E-04	4.00E-04	4.00E-04	4.00E-04
Sn	0.5	0.5	5	5	7.00E-03	7.00E-03	7.00E-03	7.00E-03
Sr	0.02	0.02	5	5	2.00E-01	2.00E-01	2.00E-01	2.00E-01
Tc	0.0001	0.0001	5	5	8.00E+00	8.00E+00	8.00E+00	8.00E+00
Th	3	3	0.5	0.5	1.00E-04	1.00E-04	1.00E-04	1.00E-04
U	0.05	0.05	0.5	0.5	7.00E-03	7.00E-03	7.00E-03	7.00E-03

Element Independent Data

Enrichment Factor		Soil Water Filled Porosity		Soil Total Porosity		Soil Dry Bulk Density	
(-)		(-)		(-)		(kg/m³)	
Library	User	Library	User	Library	User	Library	User
3	3	0.25	0.25	0.5	0.5	1400	1400

Rn-222 Data

Emanation Fraction	Effective Diffusion Coefficient

Suspended Dust Characteristics				
	Fraction of Indoor Dust Comprising of Locally Derived Soil		Annual Average Air Concentration of Respirable Particles	
	(-)		(kg/m3)	
Land Use	Library	User	Library	User
Residential with Home-Grown Produce	0.75	0.75	5.00E-08	5.00E-08
Residential without Home-Grown Produce	0.75	0.75	5.00E-08	5.00E-08
Allotments	0.375	0.375	5.00E-08	5.00E-08
Commercial/Industrial	0.75	0.75	5.00E-08	5.00E-08

(-)		(m^2 s^{-1})	
Library	User	Library	User
0.2	0.2	2.00E-06	2.00E-06

Soil Ingestion and Occupancy of Contaminated Land							
		Inadvertent Ingestion Rate for Soil and Dust		Fractional Indoor Occupancy Over Contaminated Land		Fractional Outdoor Occupancy on Contaminated Land	
		(kg (dry soil) /y)		(-)		(-)	
Land Use	Age	Library	User	Library	User	Library	User
Residential with Home-Grown Produce	Infant	5.50E-02	5.50E-02	0.875	0.875	0.125	0.125
Residential with Home-Grown Produce	Child	3.70E-02	3.70E-02	0.75	0.75	0.083	0.083
Residential with Home-Grown Produce	Adult	2.20E-02	2.20E-02	0.833	0.833	0.104	0.104
Residential without Home-Grown Produce	Infant	5.50E-02	5.50E-02	0.875	0.875	0.125	0.125
Residential without Home-Grown Produce	Child	3.70E-02	3.70E-02	0.75	0.75	0.083	0.083
Residential without Home-Grown Produce	Adult	2.20E-02	2.20E-02	0.833	0.833	0.104	0.104
Allotments	Infant	5.50E-02	5.50E-02	0.875	0.875	0.036	0.036
Allotments	Child	3.70E-02	3.70E-02	0.75	0.75	0.024	0.024
Allotments	Adult	2.60E-02	2.60E-02	0.833	0.833	0.095	0.095
Commercial/Industrial	Adult	9.20E-03	9.20E-03	0.197	0.197	0.019	0.019

Fraction of Time Spent Indoors							
		Fractional Duration of Skin Contact Indoors		Fractional Active Occupancy Indoors		Fractional Passive Occupancy Indoors	
		(-)		(-)		(-)	
Land Use	Age	Library	User	Library	User	Library	User
Residential with Home-Grown Produce	Infant	0.5	0.5	0.125	0.125	0.75	0.75
Residential with Home-Grown Produce	Child	0.5	0.5	0.083	0.083	0.667	0.667
Residential with Home-Grown Produce	Adult	0.5	0.5	0.125	0.125	0.708	0.708
Residential without Home-Grown Produce	Infant	0.5	0.5	0.125	0.125	0.75	0.75
Residential without Home-Grown Produce	Child	0.5	0.5	0.083	0.083	0.667	0.667
Residential without Home-Grown Produce	Adult	0.5	0.5	0.125	0.125	0.708	0.708
Allotments	Infant	0.5	0.5	0.125	0.125	0.75	0.75
Allotments	Child	0.5	0.5	0.083	0.083	0.667	0.667
Allotments	Adult	0.5	0.5	0.125	0.125	0.708	0.708
Commercial/Industrial	Adult	0.315	0.315	0.052	0.052	0.144	0.144

Fraction of Time Spent Outdoors							
		Fractional Duration of Skin Contact Outdoors		Fractional Active Occupancy Outdoors		Fractional Passive Occupancy Outdoors	
		(-)		(-)		(-)	
Land Use	Age	Library	User	Library	User	Library	User
Residential with Home-Grown Produce	Infant	0.178	0.178	0.083	0.083	0.042	0.042
Residential with Home-Grown Produce	Child	0.178	0.178	0.083	0.083	0	0
Residential with Home-Grown Produce	Adult	0.5	0.5	0.063	0.063	0.042	0.042
Residential without Home-Grown Produce	Infant	0.178	0.178	0.083	0.083	0.042	0.042
Residential without Home-Grown Produce	Child	0.178	0.178	0.083	0.083	0	0
Residential without Home-Grown Produce	Adult	0.5	0.5	0.063	0.063	0.042	0.042
Allotments	Infant	0.038	0.038	0.018	0.018	0.018	0.018
Allotments	Child	0.026	0.026	0.012	0.012	0.012	0.012
Allotments	Adult	0.285	0.285	0.047	0.047	0.047	0.047
Commercial/Industrial	Adult	0.233	0.233	0.013	0.013	0.006	0.006

Skin Contamination (while Indoors)					
		Soil Loading on Skin Contaminated with Soil Indoors (mg/cm²)		Maximum Fraction of Skin Exposed Indoors (-)	
Land Use	Age	Library	User	Library	User
Residential with Home-Grown Produce	Infant	0.06	0.06	0.33	0.33
Residential with Home-Grown Produce	Child	0.06	0.06	0.22	0.22
Residential with Home-Grown Produce	Adult	0.06	0.06	0.33	0.33
Residential without Home-Grown Produce	Infant	0.06	0.06	0.33	0.33
Residential without Home-Grown Produce	Child	0.06	0.06	0.22	0.22
Residential without Home-Grown Produce	Adult	0.06	0.06	0.33	0.33
Allotments	Infant	0.06	0.06	0.33	0.33
Allotments	Child	0.06	0.06	0.22	0.22
Allotments	Adult	0.06	0.06	0.33	0.33
Commercial/Industrial	Adult	0.14	0.14	0.07	0.07

Tissue Weighting Factor	
Tissue Weighting Factor for UV Exposed Skin (-)	
Library	User
0.01	0.01

Skin Contamination (While Outdoors)					
		Soil Loading on Skin Contaminated with Soil Outdoors (mg/cm²)		Maximum Fraction of Skin Exposed Outdoors (-)	
Land Use	Age	Library	User	Library	User
Residential with Home-Grown Produce	Infant	1	1	0.26	0.26
Residential with Home-Grown Produce	Child	1	1	0.15	0.15
Residential with Home-Grown Produce	Adult	0.3	0.3	0.26	0.26
Residential without Home-Grown Produce	Infant	1	1	0.26	0.26
Residential without Home-Grown Produce	Child	1	1	0.15	0.15
Residential without Home-Grown Produce	Adult	0.3	0.3	0.26	0.26
Allotments	Infant	1	1	0.26	0.26

Allotments	Child	1	1	0.15	0.15
Allotments	Adult	0.3	0.3	0.26	0.26
Commercial/Industrial	Adult	0.14	0.14	0.07	0.07

Building Type Data

Reduction in external irradiation dose rates as a result of shielding by building materials.

	Shielding Factor Applied Whilst Indoors (-)	
Building Type	Library	User
Timber	0	0
Concrete/Brick	0.9	0.9

Rn-222 Data

These parameters are only used if Rn-226 is present, to calculate the dose from the accumulation of Rn-222 gas

Building Height (m)		Building Ventilation Rate (s^{-1})	
Library	User	Library	User
3	3	8.33E-05	8.33E-05

Human Characteristics Data

Information describing human anatomical and physiological characteristics used in assessment calculations.

Body Weight and Surface Area

		Body Weight (bw) (kg)		Fraction of Skin that is UV Exposed (-)	
Sex	Age	Library	User	Library	User
Male	Infant	11	11	0.167	0.167
Male	Child	37	37	0.167	0.167
Male	Adult	81	81	0.167	0.167
Female	Infant	11	11	0.167	0.167
Female	Child	37	37	0.167	0.167
Female	Adult	68	68	0.167	0.167

Respiration

		Active Respiration Rate (m^3/h)		Passive Respiration Rate (m^3/h)	
Sex	Age	Library	User	Library	User
Male	Infant	0.339	0.339	0.124	0.124
Male	Child	1.103	1.103	0.404	0.404
Male	Adult	1.456	1.456	0.485	0.485
Female	Infant	0.32	0.32	0.117	0.117

Female	Child	1.1	1.1	0.403	0.403
Female	Adult	1.234	1.234	0.411	0.411

Origin of Food and Amount of Soil on Vegetables

	Fraction of Consumption Derived from Contaminated Area		Soil Contamination of Home-Grown Vegetables	
	(-)		(kg(dw)/kg(fw))	
Crop	Library	User	Library	User
Brussels Sprouts	0.87	0.87	0.001	0.001
Cabbage	0.92	0.92	0.001	0.001
Carrot	0.7	0.7	0.0001	0.0001
Leafy Salads	0.51	0.51	0.001	0.001
Onion (shallots and leeks)	0.91	0.91	0.001	0.001
Potato	0.66	0.66	0.0002	0.0002

Consumption Rates

		Consumption Rate of Vegetables (kg(fw)/kg(bw)/y)	
Age	Crop	Library	User
Infant	Brussels Sprouts	4.75E-01	4.75E-01
Infant	Cabbage	5.48E-01	5.48E-01
Infant	Carrot	6.57E-01	6.57E-01
Infant	Leafy Salads	4.02E-01	4.02E-01
Infant	Onion (shallots and leeks)	3.36E-01	3.36E-01
Infant	Potato	2.74E+00	2.74E+00
Child	Brussels Sprouts	2.48E-01	2.48E-01
Child	Cabbage	2.30E-01	2.30E-01
Child	Carrot	3.65E-01	3.65E-01
Child	Leafy Salads	1.93E-01	1.93E-01
Child	Onion (shallots and leeks)	2.30E-01	2.30E-01
Child	Potato	2.08E+00	2.08E+00
Adult	Brussels Sprouts	2.56E-01	2.56E-01
Adult	Cabbage	2.45E-01	2.45E-01
Adult	Carrot	2.37E-01	2.37E-01
Adult	Leafy Salads	1.79E-01	1.79E-01
Adult	Onion (shallots and leeks)	1.61E-01	1.61E-01
Adult	Potato	1.24E+00	1.24E+00

Constants

Density of Water	1000 (kg/m³)
Rn-222 Decay Constant (s^{-1})	2.10E-06
Non-Rad Calculations	
Annual respired volume of air with indoors (m^3/y)	1185.885

Annual respired volume of air with indoors (m^3/y)	292.1022
Ratio of the area of skin contaminated to the area of skin exposed to Ultra-violet	1
Crop Calculations	
Total consumption rate of all vegetables, which are homegrown (kg/y)	40.62859
Total consumption rate of soil on all vegetables, which are homegrown (kg/y)	0.020176

5.3 RCLEA References:

U.K. Government Department for Environment, Food and Rural Affairs (2011), *The Radioactively Contaminated Land Exposure Assessment Methodology – Technical Report*, CLR-14, Version 1.2. available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/316279/Radioactively_Contaminated_Land_Exposure_Assessment_Methodology_Technical_Report.pdf

VI. Radioactive Soil Remediation Standards (RaSoRS):

RaSoRS is an Excel-based model developed in 2003 by the Bureau of Environmental Radiation of the State of New Jersey to provide technical support to the Site Remediation Program (Figure 4). RaSoRS contains a total of 7 radionuclides with their progenies (U-238, U-234, Th-230, Ra-226, U-235, Ac-227 and Th-232). The RaSoRS spreadsheet may be found at: http://www.nj.gov/dep/rpp/rms/agreedown/NJrasorsver60.xls.

6.1 RaSoRS Exposure Scenarios and Pathways:

RaSoRS has two construction scenarios (Basement and Slap-on-Grade) for two site use scenarios (Residential and Commercial). It can calculate doses from external gamma exposure, ingestion of crops, ingestion of soil, ingestion of water, inhalation of dust and radon.

6.2 RaSoRS Recommended Default Input Parameters

ASSUMPTIONS PERTAINING TO EXCAVATION SCENARIO		
Uncontaminated surface soil lost from grading (ft):	1	
Parameters Specific to Construction Scenario	**Basement**	**Slab on Grade**
Depth of excavation (ft):	7	4
Width of excavation (ft):		2
Parameters Specific to Site Use Scenario	**Residential**	**Commercial**
Building length (ft):	40	60
Building width (ft):	25	40
Lot size ((ft²):	10,890	87,120
Fraction of time spent indoors on site:	68%	18%
Fraction of time spent outdoors on site:	8%	5%

ASSUMPTIONS PERTAINING TO RADON PATHWAY	
Radon to radium ratio (pCi/l per pCi/g):	1.5

ASSUMPTIONS PERTAINING TO EXTERNAL GAMMA PATHWAY		
Shielding factor through basement or slab:	0.2	
Shielding factor through walls:	0.8	
Shielding factor outside:	1	
Cover coefficient (% through 1 ft clean soil):	10%	
Parameters Specific to Site Use Scenario	**Residential**	**Commercial**
Area factor for under basement or slab:	0.53	0.66
Area factor for side contribution:	0.43	0.34
Area factor for four basement walls:	1.45	1.62
Area factor for outside:	0.96	1

ASSUMPTIONS PERTAINING TO INTAKE PATHWAYS		
Indoor dust level as percent of outdoor:	40%	
resuspension dilution length (ft):	10	
Drinking water consumption rate (l/yr):	700	
Root depth (ft):	3	
Parameters Specific to Site Use Scenario	**Residential**	**Commercial**
Soil ingestion rate (g/yr):	70	12.5
Outdoor mass loading (µg/m³):	100	200
Indoor on site breathing rate of adult (m³/hr):	0.63	1.4
Outdoor on site breathing rate of adult (m³/hr):	1.4	1.4
Homegrown crop ingestion rate (g/yr):	17,136	0

6.3 RaSoRS References:

New Jersey Department of Environmental Protection (1999), *Development of Generic Standards for Remediation of Radioactively Contaminated Soils in New Jersey, A Pathways Analysis Approach*, Bureau of Environmental Radiation, Trenton, NJ.

VII. WISMUT

The WISMUT model, "Calculation Guide Mining", is developed by the Germany Federal Laender and the WISMUT GmbH to assess radiation exposure for the public and workers due to environmental radioactivity resulting from mining. The name "WISMUT" refers to the areas in Saxony and Thuringia in Germany that were adversely affected by more than 40 years of unrestrained mining and processing of uranium ores. The WISMUT model is developed with special considerations for the WISMUT region, such as levels of natural background for all relevant environmental media in the area. It is applicable for remediation, decommissioning, reuse of mining plants and installations. The WISMUT model is not available in English and not accessible due to a copyright agreement; however, an English language version of the WISMUT model User Guide was provided for this analysis.

7.1 WISMUT Exposure Scenarios and Pathways

WISMUT can be used for the following scenarios: indoors (dwellings and public buildings), commercial buildings, underground workplaces (only inhalation of radon and its short-lived decay products), outdoors, ingestion of breast milk, and locally produced food (vegetable and animal products, as well as water). It can calculate doses from external exposure to gamma radiation from soil, exposure from inhalation of dust, exposure from inhalation of radon and its short-lived decay products, exposure from ingestion of breast milk, exposure from ingestion of locally produced foods (drinking water, fish, milk and milk products, meat and meat products, leafy vegetables and other vegetable products), and exposure from direct soil ingestion.

7.2 WISMUT Recommended Default Input Parameters

Consumption Rates							
Reference Person	≤ 1 a	1 - 2 a	2 - 7 a	7 - 12 a	12 -17 a	> 17 a	Worker
Drinking Water Intake (Liter/year)	55	100	100	150	200	350	
Milk Including Milk products (Liter/year)	45	160	160	170	170	130	
Processed milk products* oder breast milk	200						
Meat Including meat products (kg/year)	5	13	50	65	80	90	
Fish &Seafood consumption (kg/year)	0.5	3	3	4.5	5	7.5	
Vegetable products	75	138	227	259	271	253	
Cereals, cereal products	12	30	80	95	110	110	
Fresh fruit, fruit products, juice	25	45	65	65	60	35	
Potatoes, root vegetables, juice	30	40	45	55	55	55	
Leafy vegetables	3	6	7	9	11	13	
Vegetables, vegetable products, juice	5	17	30	35	35	40	
Soil consumption (kg/year)	0	5 E-5	3E-5	6E-6	6E-6	6E-6	6E-6
Breathing Rates (m³/h)	0.12	0.22	0.36	0.64	0.84	0.93	1.2
Conversion factor, to obtain effective dose for reference person from ambient dose equivalent	0.8	0.7	0.7	0.7	0.6	0.6	0.6

* Another 160 L a^{-1} are added to the infant's annual drinking water quantity of 55 L a^{-1} when it is assumed that the infant is not being breastfed but is only given processed milk products that have been produced outside the region and can be considered uncontaminated. It is assumed that 0.2 kg concentrate (equivalent to 1 L milk) are dissolved in 0.8 L of water.

Shielding Factors	
Outdoors	1
Indoors, solid construction buildings (brick, concrete)	0.1
Indoors, lightweight construction buildings (wooden)	0.3

Inhalation dose coefficient for radionuclide and inhalation dose coefficient of the radionuclide mixture for reference person:

^{238}U-series:	≤ 1 yr	1 - 2 yr	2 - 7 yr	7 - 12 yr	12 - 17 yr	> 17 yr	Worker
^{238}U	1.2E-5	9.4E-6	5.9E-6	4.0E-6	3.4E-6	2.9E-6	1.6E-6
^{234}U	1.5E-5	1.1E-5	7.0E-6	4.8E-6	4.2E-6	3.5E-6	2.1E-6
^{230}Th	4.0E-5	3.5E-5	2.4E-5	1.6E-5	1.5E-5	1.4E-5	7.2E-6
^{226}Ra	1.5E-5	1.1E-5	7.0E-6	4.9E-6	4.5E-6	3.5E-6	2.2E-6
^{210}Pb	5.0E-6	3.7E-6	2.2E-6	1.5E-6	1.3E-6	1.1E-6	1.1E-6
^{210}Po	1.5E-5	1.1E-5	6.7E-6	4.6E-6	4E-6	3.3E-6	2.2E-6
^{235}U-series:							
^{235}U	1.3E-5	1.0E-5	6.3E-6	4.3E-6	3.7E-6	3.1E-6	1.8E-6
^{231}Pa	2.2E-4	2.3E-4	1.9E-4	1.5E-4	1.5E-4	1.4E-4	8.9E-5
^{227}Ac	1.7E-3	1.6E-3	1.0E-3	7.2E-4	5.6E-4	5.5E-4	6.3E-4
^{232}Th-series:							
^{232}Th	5.4E-5	5.0E-5	3.7E-5	2.6E-5	2.5E-5	2.5E-5	1.2E-5
^{228}Ra	1.5E-5	1.0E-5	6.3E-6	4.6E-6	4.4E-6	2.6E-6	1.7E-6
^{228}Th	1.6E-4	1.3E-4	8.2E-5	5.5E-5	4.7E-5	4.0E-5	3.2E-5
Mixture	1.9E-4	1.7E-4	1.1E-4	8.0E-5	6.8E-5	6.3E-5	5.0E-5

Ingestion dose coefficient for radionuclide and ingestion dose coefficient of the radionuclide mixture for reference person:

^{238}U-series:	≤ 1 yr	1 - 2 yr	2 - 7 yr	7 - 12 yr	12 - 17 yr	> 17 yr	Worker
^{238}U	3.4E-7	1.2E-7	8.0E-8	6.8E-8	6.7E-8	4.5E-8	4.4E-8
^{234}U	3.7E-7	1.3E-7	8.8E-8	7.4E-8	7.4E-8	4.9E-8	4.9E-8
^{230}Th	4.1E-5	4.1E-7	3.1E-7	2.4E-7	2.2E-7	2.1E-7	2.1E-7
^{226}Ra	4.7E-6	9.6E-7	6.2E-6	8.0E-7	1.5E-6	2.8E-7	2.8E-7
^{210}Pb	8.4E-6	3.6E-6	2.2E-6	1.9E-6	1.9E-6	6.9E-7	6.8E-7
^{210}Po	2.6E-5	8.8E-6	4.4E-6	2.6E-6	1.6E-6	1.2E-6	2.4E-7
^{210}Po for soil ingestion	5.2E-6	1.8E-6	8.8E-7	5.2E-7	3.2E-7	2.4E-7	
^{235}U-series:							
^{235}U	3.5E-7	1.3E-7	8.5E-8	7.1E-8	7.0E-8	4.7E-8	4.6E-8
^{231}Pa	1.3E-5	1.3E-6	1.1E-6	9.2E-7	8.0E-7	7.1E-7	7.1E-7
^{227}Ac	3.3E-5	3.1E-6	2.2E-6	1.5E-6	1.2E-6	1.1E-6	1.1E-6
^{232}Th-series:							
^{232}Th	4.6E-6	4.5E-7	3.5E-7	2.9E-7	2.5E-7	2.3E-7	2.2E-7
^{228}Ra	3.0E-5	5.7E-6	3.4E-6	3.9E-6	5.3E-6	6.9E-7	6.7E-7
^{228}Th	3.7E-6	3.7E-7	2.2E-7	1.5E-7	9.4E-8	7.2E-8	7.0E-8
Mixture	4.6E-5	1.4E-5	7.9E-6	5.8E-6	5.5E-6	2.6E-6	1.6`E-6

Exposure site	Equilibrium factor Rn-222
On a mining installation or facility	
Indoors and outdoors	0.4
In the vicinity of a mining installation or facility	
Indoors and outdoors	0.4

Values to calculate the radionuclide transport:	
Fraction of time per year spent on the pasture by grazing animals	0.5
Fraction of activity deposited on the plant during spray irrigation	0.3
Daily water consumption by cattle (L d-1)	75
Daily ingestion of pasture forage (FM) (kg d-1)	65
Daily soil ingestion by cattle when grazing on the pasture (DM) (kg d-1)	0.5
Proportion of local food production	
Milk, Meat, Fish, Leafy Vegetable, Vegetables, Root Vegetables, Fruit	0.5
Drinking Water, Breast Milk, Processed Milk	1
Contamination time for plants during the growth period	
vegetable products except for leafy vegetables (60 days)	5.2E 6 (sec.)
leafy vegetables (60 days)	5.2E 6 (sec.)
pasture plants (30 days)	2.6E 6 (sec.)
Time of surface contamination of plants due to spray irrigation during the growth period	
time until the same piece of pasture is fed down again (30 days)	2.6E 6 (sec.)
average growing period of vegetable productions except for leafy vegetables, and of leafy vegetables respectively (60 days)	5.2E 6 (sec.)
Spray irrigation rate during grazing time and growth period of vegetable products ($L\ m^{-2}\ s^{-1}$)	1.2E -5
Yield or vegetation density (FM)	
yield of leafy vegetables ($kg\ m^{-2}$)	1.6
yield of vegetable products except for leafy vegetables ($kg\ m^{-2}$)	2.4
plant cover density of pasture plants ($kg\ m^{-2}$)	0.85
Effective rate constant for the retention of radionuclide r on the plant	
Effective rate constant: (Physical decay constant of radionuclide r, s^{-1}) + (Residence constant for the retention of the radionuclides on the plant)	
Residence constant for the retention of the radionuclides on the plant (residence time 14 days) (s^{-1})	5.7 E -7

Transfer factors for pasture plants and food as well as concentration factors for fish related to radionuclide.

	T.F to PP	T.F to LV; PL	T.F to Mi	T.F to Me	T.F to BM	T.F to BM, Inh	T.F to Fi
	Bq/kg (FM)/ Bq/kg (DM)		d/kg	d/kg	d/kg	d/kg	L/kg
U	3E-3	3E-3	5E-4	4E-4	2E-2	1E-1	2
Pa	3E-3	3E-3	5E-6	5E-3	6E-4	2E-1	30
Th	2E-3	5E-4	5E-6	2E-4	2E-2	2E-2	30
Ac	3E-3	3E-3	2E-5	3E-3	6E-4	4E-1	30
Ra	1E-2	5E-3	3E-3	9E-4	2E-1	2E-1	10
Pb	1E-2	7E-3	3E-4	4E-4	2E-1	1E-1	60
Po	1E-2	5E-3	3E-4	5E-3	6E-1	2E-1	300

T.F to PP= Transfer factor from soil to pasture plants (These transfer factors account for the uptake of radionuclides not only via roots but also via surface plant components due to local contamination).

T.F to LV; PL= Transfer factor from soil to leafy vegetables and none leafy vegetables. (These transfer factors account for the uptake of radionuclides not only via roots but also via surface plant components due to local contamination).

T.F to Mi = Transfer factor from forage, cattle trough water and ingested soil to milk

T.F to Me= Transfer factor from forage, cattle trough water and ingested soil to meat

T.F to BM= Foodstuff to breast milk transfer factor for radionuclide

T.F to BM, Inh= Inhaled-dust-to-breast milk transfer factor for radionuclide

T.F to Fi= Concentration factor for radionuclide r in fish.

^{222}Rn concentration or potential alpha energy concentration of the short-lived ^{222}Rn decay products of the natural background outdoors. The value of potential alpha energy concentration of the short-lived 222Rn decay products was calculated from the 222Rn concentration using an equilibrium factor of 0.4.

^{222}Rn concentration	10 Bq m^{-3}
Potential alpha energy concentration of short-lived ^{222}Rn decay products	2.22E^{-8} J m^{-3}

WISMUT has the following natural background tables used in the model:

- General values of natural background activity concentration for a particle-bound radionuclide.
- ^{222}Rn concentration or potential alpha energy concentration of the short-lived ^{222}Rn decay products of the natural background outdoors.
- General values of natural background activity concentration of radionuclide in foodstuff.
- General values of natural background activity concentration of radionuclide in the upper Soil, soil layer (0 – 10 cm for pasture soil, 0 – 30 cm for arable and garden soil, 0 – 30 cm for calculating external radiation exposure) and of activity concentrations in the dust Soil (0.02), fraction and in the fine grain fraction of soil (dry mass).
- General values of natural background activity concentration of the radionuclide r in surface water in spray irrigation water and in cattle watering trough water.
- General values of natural background activity concentration of radionuclide in pasture plants (fresh mass).
- General values of natural background soil contamination rate of radionuclide from dry dust deposition.

7.3 WISMUT Reference:

Department Radiation Protection and Environment Salzgitter (2011), *Calculation Guide Mining; Calculation Guide for the Determination of Radiation Exposure due to Environmental Radioactivity Resulting from Mining Department Radiation Protection and Environment*. Germany.

VIII. NCRP Report No. 129

The National Council on Radiation Protection and Measurements (NCRP) published a report entitled "Recommended Screening Limits for Contaminated Surface Soil and Review of Factors Relevant to Site Specific Studies", report No. 129. It lists screening guidance for over 200 radionuclides with half-lives greater than 30 days. The limits were calculated by dividing 0.25 mSv by the calculated maximum screening total dose per unit soil concentration in Sieverts.

8.1 NCRP Exposure Scenarios and Pathways

The NCRP report no. 129 contains soil guidelines for several Land-Use Scenarios, such as Agricultural (AG), Heavily Vegetated Pasture (PV), Sparsely Vegetated Pasture (PS), Heavily Vegetated Rural (RV), Sparsely Vegetated Rural (RS), Suburban (SU), No Food Suburban (SN), and Construction, Commercial, Industrial (CC). The exposure pathways considered in NCRP include external radiation exposure, beta-ray skin dose, ingestion of contaminated foodstuffs, direct and indirect ingestion of soil by human and animals, and both indoor and outdoor inhalation of resuspended material.

8.2 NCRP Recommended Default Input Parameters

Food consumption rate	
Fruit, Vegetable and Grains (kg/yr)	300
Milk consumption (Liter/yr)	200
Meat and poultry consumption (kg/yr)	100

Inhalation rates used for calculating adult screening doses for land-use scenario considered (m^3/day)

	Land use scenario						
	AG	PV	PS	RV	RS	SU/SN	CC
outdoor	35	35	35	30	30	25	35
GSD	1.2	1.2	1.2	1.2	1.2	1.2	1.2
indoor	-	-	-	20	20	20	-
GSD	-	-	-	1.2	1.2	1.2	-

GSD: Geological Standard Deviation, S.D: Standard Deviation.

Soil ingestion rates and number of days of exposure (T) used for screening dose calculations.				
Land-Use Scenario	Adult	Child	Time (day/year)	Range
Agricultural	0.1	-	270	180-360
Heavily Vegetated Pasture	0.05	-	270	180-360
Sparsely vegetated pasture	0.1	-	270	180-360
Heavily Vegetated rural	0.05	0.1	270	180-360
Sparsely Vegetated rural	0.1	0.2	270	180-360
Suburban	0.05	0.1	270	180-360
Construction, etc	0.1	-	180	90-270

Animal Consumption Rates (kg/day)		
	Fodder	Range
Milk cows	16	8-25
Beef cattle, game	8	4-12
Pigs	2.4	2-3
Calves	1.9	1.5-3.5
Lamb	1.1	0.5-2.0
Chicken	0.07	0.05-0.15

Occupancy Factors			
Percent of time spent:	Indoor on-site (%)	Outdoor on-site (%)	Time off-site (%)
Agricultural	40	0	60
Heavily Vegetated Pasture	30	0	70
Sparsely vegetated pasture	30	0	70
Heavily Vegetated rural	40	50	10
Sparsely Vegetated rural	40	50	10
Suburban	40	50	10
Construction, etc.	30	0	70

Shielding Factors
Radionuclides dependents, Appendix C

	AG	PV	PS	RV	RS	SU/SN	CC
Soil water	0.15	0.10	0.05	0.15	0.05	0.15	0.05
S.D	0.15	0.05	0.05	0.05	0.05	0.05	0.05
Child/adult correction factor, used only when calculating doses to infants and children	1	1	1	1.3	1.3	1.3	1
	-	-	-	0.1	0.1	0.1	-
Annual outdoor air concentration ($nBq\ m^{-3}$ per $Bq\ kg^{-1}$)	40	20	400	10	400	50	600
S.D	-	-	-	0.3	0.3	0.3	-
Fraction of total vegetables, fruit from site. (%)	50	0	0	30	15	15	0
Range	20-80	-	-	10-50	5-25	5-25	-
Fraction of total milk from site (%)	0	100	100	100	100	0	0
Fraction of total meat from site . (%)	0	100	100	30	10	0	0
Range	-	-	-	10-50	0-20	-	-
Fraction of total feed from site. (%)	-	75	66	25	15	-	-
Range	-	60-90	46-86	15-35	10-20	-	-
Fraction of total animal feed from site (%)	-	75	66	25	15	-	-
Range	-	60-90	46-86	25-35	10-20	-	-

Land use independent:		
Mean concentration in soil (Bq kg-1 dry)	1.0 (mean)	S.D. = 0.5
Density of soil *(g/*cm^{-3})	1.6	S.D. = 0.1
Adult external radiation dose factor (Sv d-1 per Bq kg-1)	Nuclide dependent	CV = 0.1-0.3
Adult inhalation dose factor (Sv Bq-1)	Nuclide dependent	GSD = 1.4-2.2
Child/adult correction factor-used only when calculating doses to children	Nuclide dependent	
Feed to meat transfer factor (d kg-1)	Nuclide dependent	GSD = 1.2-2.8
Feed to milk transfer factor (d L-1).	Nuclide dependent	GSD = 1.6-2.5
Adult ingestion dose factor (Sv Bq-1)	Nuclide dependent	GSD = 1.3-2.5
$(C/A)_{ing}$, $(I/A)_{ing}$:Child/adult correction factor- used only when calculating dose to infant or child.(Ing.)	Nuclide dependent	
$(C/A)_{veg}$:Child/infant correction factor-used only when calculating dose to infant or child.(Veg.)	Max [0.65 $(C/A)_{ing}$,0.34 $(I/A)_{ing}$]	
$(C/A)_{milk}$:Child/infant correction factor-used only when calculating dose to infant or child.(Milk)	Max [1.0 $(C/A)_{ing}$,1.1 $(I/A)_{ing}$]	
$(C/A)_{meat}$:child/infant correction factor-used only when calculating dose to infant or child, (Meat)	Max [0.7 $(C/A)_{ing}$,0.3 $(I/A)_{ing}$]	
Bv =root uptake factor (Bq kg-'wet vegetable per Bq kg-1 dry soil)	Nuclide dependent	GSD = 2.5-3.0
Bv' = resuspension/soil adhesion (Bq kg-1 wet vegetable per Bq kg-1 dry soil)	Nuclide dependent	GSD = 2.5-3.0
Bf =root uptake factor (Bq kg-1 dry fodder per Bq kg-1 dry soil)	Nuclide dependent	GSD = 2.5-3.0)
Bf' = resuspension/soil adhesion (Bq kg-1 dry fodder per Bq kg-1 dry soil)	Nuclide dependent	GSD = 2.5-3.0

8.3 NCRP References:

NCRP. (1999). *Recommended screening limits for contaminated surface soil and review of factors relevant to site-specific studies*. NCRP Report No. 129. Bethesda, MD