Overview of Radiation Risk and Dose Assessment Models for Radioactively Contaminated Sites and Selected Default Input Parameters

By

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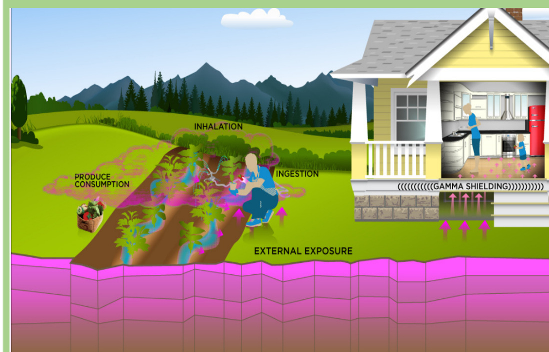

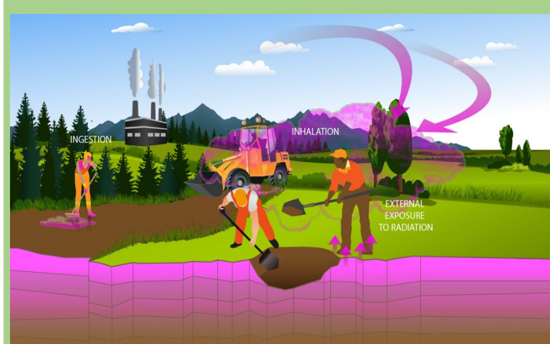

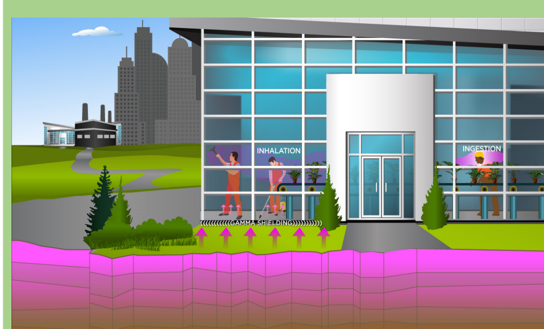

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I. INTRODUCTION

The release of radioactive materials to the environment or the atmosphere can pose risks to ecosystems and people. Heavily radioactively contaminated sites have been found in many countries, where drinking water and soil are threatened due to the radioactive contamination. The potential risks from radionuclides have become a well-known problem. People can be exposed via different media (soil, water and air). Many agencies have developed and/or recommended particular radiation risk or dose assessment models for addressing contaminated sites, which become an important tool for decision makers. Other Agencies have developed look-up tables in reports for soil screening guidelines.

Modeling and monitoring are necessary to comply with regulations and 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 may be used. Advanced assessment requires site-specific data for the relevant scenarios and pathways. Site-specific data can reduce uncertainties and make the assessment more realistic.

There are many radiation risk assessment models used in the United States and other countries; however, they do not have identical assumptions, scenarios or calculations. Some models are fairly simple to use and address a more narrow scope of scenarios; others are more technically advanced and deal with a wide range of scenarios. Generally, the models use a set of calculations, where the inputs are the parameters for the relevant exposure scenario described by mathematical equations and the output is risk or dose. They are simplified by technical and scientific assumptions to represent a real-world environmental problem. They are also associated with uncertainties of scenarios and parameters. The general components of the models are similar in terms of selecting radionuclides, media, type and scenario of exposure, receptor and output (risk/dose). Some models have been developed as software and others as an Excel spreadsheet or reports.

This document is an overview of radiation risk and dose assessment models, including the exposure scenarios and pathways and review of selected default input parameters used by each model. The objective of this overview is to make recommendations on technical and practical issues to the U.S. Environmental Protection Agency (EPA) Office of Superfund Remediation and Technology Innovation (OSRTI), facilitating better understanding of each agency's modeling approach and identifying the similarities and differences between these agencies in the risk and dose assessment of radioactively contaminated sites. This document is not intended to be a direct comparison between models, because each model was formed and derived based on a specific regulatory frame that could be different from one agency to another.

This document also discusses several models issued for chemical risk assessment that are generally consistent with the agencies' radiation models. The radiation sites addressed by OSRTI also have chemical contamination, and its regulations and policies for Superfund sites call for risk assessments to demonstrate that the selected remedy will meet the one in 10,000 to one in a million cancer (10^{-4} to 10^{-6}) risk range for all carcinogens. This means the cancer risks from chemical carcinogens and radionuclides are summed. Since it has been EPA's longstanding policy that similar models should be used for the chemical and radionuclide risk assessments so that the results are consistent when summed, it was deemed prudent to include, in this study, chemical models issued by governmental entities that also have radionuclide models.

This study did not look at transport functions of some of the models. The models issued by EPA for Superfund chemical and radionuclide risk assessments are steady state models without source depletion from mechanisms such as runoff, as are the risk assessment approaches for Superfund sites issued by state regulatory programs. Therefore, it was determined that looking at such aspects in other models, which are generally not used in Superfund risk assessments, would not be useful to the study sponsors.

This study focused on models that were issued or recommended by regulatory programs. The study sponsors were most interested in reviewing the default parameters and risk assessment approaches that other governmental agencies had adopted. Attempting to include every model that has been used for radiation risk or dose assessment at a site would have greatly expanded the scope of the project and hindered its completion.

This study also focused solely on deterministic, rather than probabilistic, models. The models issued and recommended by EPA for radiation risk and dose assessment are deterministic models. EPA's policy for Superfund radiation risk assessment states that probabilistic risk assessment may be used to provide quantitative estimates of the uncertainties in the risk assessment; however, probabilistic estimates of risk may then be presented as a supplement to, not instead of, the deterministic methods.

During the study development, this project was discussed with different groups to see if there was further information/models that would be useful to include. This research project was presented or discussed in the following conferences and meetings:

- Health Physics Society Meeting, 22 January 2017, Bethesda, MD, USA
- Waste Management Conference, March 5, 2017, Phoenix, AZ, USA

- The Interagency Performance & Risk Assessment Community of Practice (P&RA CoP), hosted by the US Department of Energy, April 19, 2017, USA
- IAEA MODARIA II Working Group 1: Assessment and Decision Making of Existing Exposure Situations for NORM and Nuclear Legacy Sites, June 30, 2017, Brussels, Belgium

II. MODELS OVERVIEW

2.1 Preliminary Remediation Goals (PRG)

Preliminary Remediation Goals for Radionuclide Contaminants at Superfund Sites (PRG) is an electronic calculator developed by the U.S. Environmental Protection Agency. 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 (Figure 1).

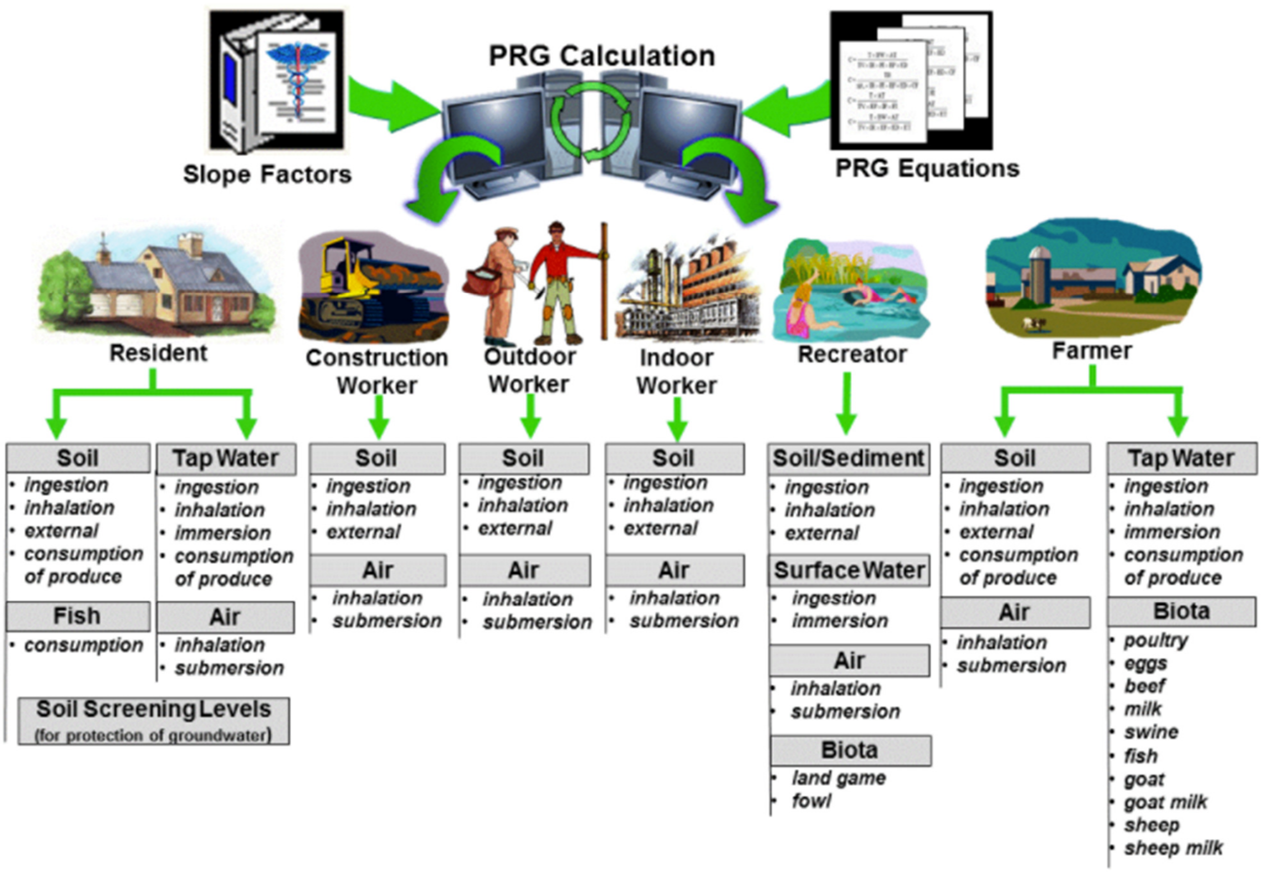


Figure 1: PRG calculator website homepage.

The calculator also presents PRGs to protect groundwater, which are determined by calculating the concentration of radioactively contaminated water leaching from radioactively contaminated soil to groundwater that will meet maximum contaminant levels (MCLs) or risk-based concentrations. 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. [1]

The PRG calculator is also consistent with EPA's Regional Screening Level for Chemical Contaminants at Superfund Sites (RSL) calculator, which is the recommended risk assessment model for chemicals in soil, water, and air and may be found at: https://www.epa.gov/risk/regional-screening-levels-rsls. The RSL calculator is almost identical to the chemical risk assessment calculator for emergency and time-critical removal actions, called the Regional Removal Management Levels for Chemicals (RMLs), which may be found at: https://epa-rals.ornl.gov/.

2.1.1 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/2D for shielding from radiation in an external exposure scenario.

2.1.2 RSL Exposure Scenarios and Pathways

Scenario/ Land use	Media
Resident	Soil, air, tap water, and fish
Composite worker	Soil and air.
Outdoor worker	Soil and air
Indoor worker	Soil and air
Construction worker—standard unpaved road vehicle traffic (site-specific only)	Soil and air
Construction worker—wind erosion and other construction activities (site-specific only)	Soil and air
Recreator (site-specific only)	Soil, air, surface water, game and fowl
Farmer	Scenario not included
Soil to groundwater	Soil

2.1.3 RML Exposure Scenarios and Pathways

Scenario/ Land use	**Media**
Resident	Soil and tap water
Composite worker	Soil
Outdoor worker	Scenario not included
Indoor worker	Scenario not included
Construction worker—standard unpaved road vehicle traffic (site-specific only)	Scenario not included
Construction worker—wind erosion and other construction activities (site-specific only)	Scenario not included
Recreator (site-specific only)	Scenario not included
Farmer	Scenario not included
Soil to groundwater	Scenario not included

2.2 Dose Compliance Concentration (DCC)

Dose Compliance Concentration for Radionuclides at Superfund Sites (DCC) is also an electronic calculator developed by the U.S. Environmental Protection Agency to address Applicable or Relevant and Appropriate Requirements (ARARs) that are expressed in terms of millirem per year. An approach similar to that taken for calculation of PRGs was also used to calculate "compliance concentrations" based upon various methods of dose calculation (Figure 2).

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. DCCs may be calculated for 1255 radionuclides. 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]

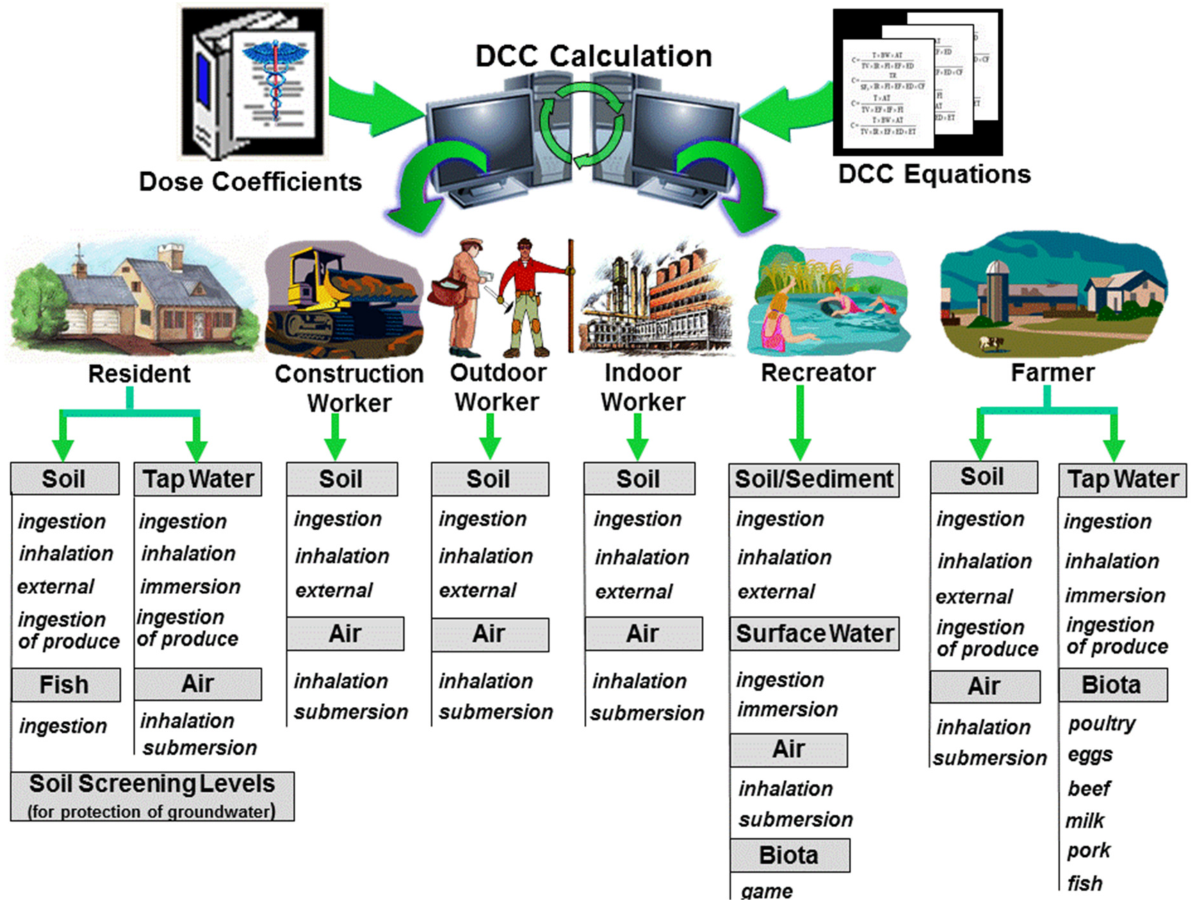


Figure 2: DCC calculator website homepage.

2.2.1 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	Soil
Cover Layer	May be added to soil/ 2D for shielding from radiation in an external exposure scenario.

2.3 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]

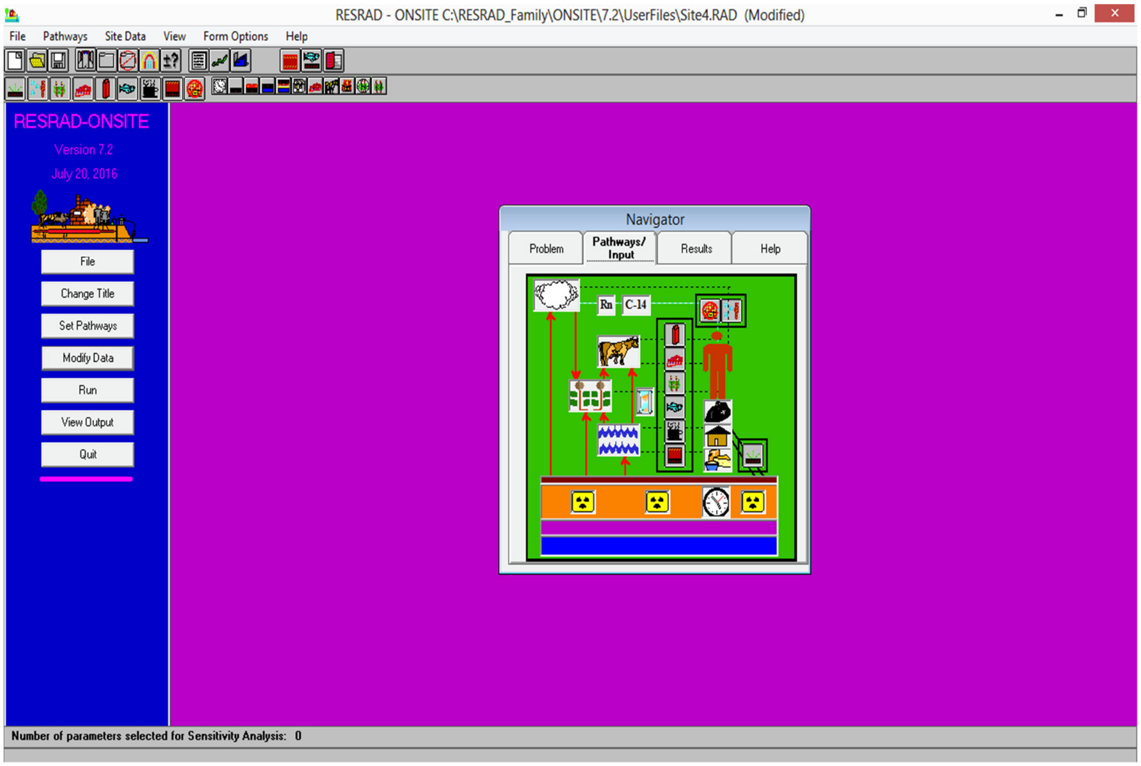


Figure 3: RESRAD-ONSITE.

2.3.1 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.

2.4 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. [4]

The State of New Jersey has also issued Excel spreadsheets for assessing risks of chemicals in soil, groundwater, and surface water, which may be found at: http://www.nj.gov/dep/srp/guidance/rs/.

2.4.1 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.

	A	B	C	D	E	F	G	H
1		SITE INFORMATION			PATHWAY RESTRICTIONS			
2		vertical extent of contamination (ft):	0.0			Basement?	y	
3		uncontaminated surface soil (ft):	0.0			External?	y	
4		Unrestricted (Residential)?	y			Soil Ingestion?	y	
5						Inhalation?	y	
6						Drinking Water?	y	
7						Crop Ingestion?	y	
8						Radon?	y	
9								
10	Subchain	proposed residual soil concentration (pCi/g)	background soil concentration (pCi/g)	allowable soil concentration increment for basement (pCi/g)	allowable soil concentration increment for slab-on-grade (pCi/g)	fraction of allowable concentration for basement	fraction of allowable concentration for slab-on-grade	resultant dose increment (mrem/yr)
11	U238	0.0	0.0	133	125	0.0%	0.0%	0.0
12	U234	0.0	0.0	193	199	0.0%	0.0%	0.0
13	Th230	0.0	0.0	124	125	0.0%	0.0%	0.0
14	Ra226	0.0	0.0	3	3	0.0%	0.0%	0.0
15	U235	0.0	0.0	52	44	0.0%	0.0%	0.0
16	Ac227	0.0	0.0	3	3	0.0%	0.0%	0.0
17	Th232	0.0	0.0	2	2	0.0%	0.0%	0.0
18				SUM OF FRACTIONS =		0%	0%	0.0
19								mrem/yr
20					Radon-based Ra226 standard			slab-on-grade
21						*NOT Radon-limiting*		

Disclaimer | Results | Assumed Parameters | Subchain Factors | Calculated Paramete ...

Figure 4: RaSoRS spreadsheet.

2.5 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. [5]

2.5.1 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. [5]

2.6 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 (Figure 5).

Figure 5: RCLEA spreadsheet.

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. [6]

To assess risks from chemicals, the UK Environmental Agency has also issued Contaminated Land Exposure Assessment (CLEA). RCLEA is consistent with the CLEA approach for non-radioactive contamination in: 1) three reference land uses (residential, allotment, commercial/industrial), 2) default input data, and 3) similar equations for calculating the potential intake of radionuclides in contaminated soil. CLEA may be downloaded at: https://www.gov.uk/government/publications/contaminated-land-exposure-assessment-clea-tool.

2.6.1 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. [6]

2.7 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) [7].

2.7.1 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	

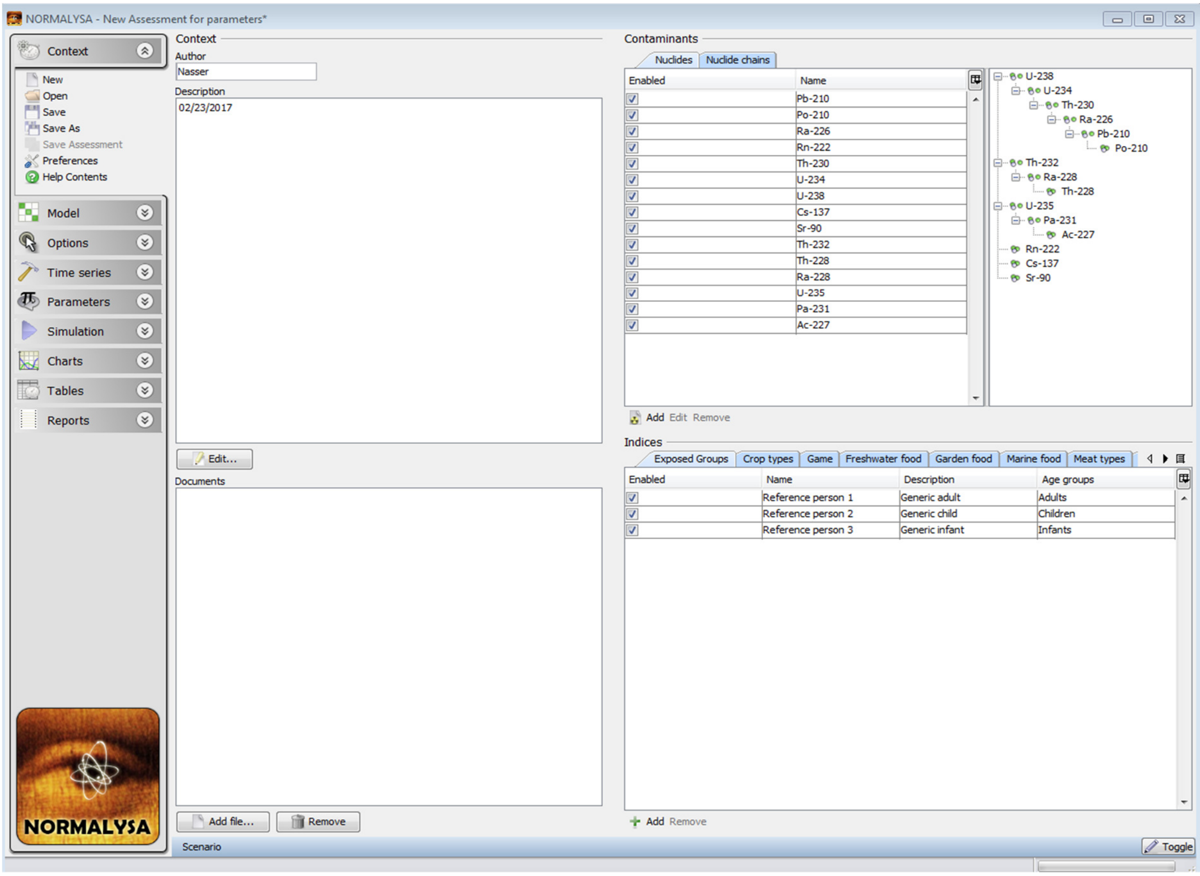


Figure 6: NORMALYSA.

2.8 Screening Model for Environmental Assessment (CROM)

CROM is a model developed by the University of Madrid and the Environmental Impact of the Energy Department (CIEMAT) to calculate radionuclide concentrations in different environments and their impact in the nutritional chain as well as dose in human beings (Figure 7).

The model is based on Safety Report Series No. 19, published by the International Atomic Energy Agency (IAEA), “Generic Models for Use in Assessing the Impact of Discharges of Radioactive Substances to the Environment”. CROM has a default database with 151 Radionuclides and can be used for continuous and prolonged release to the environment. CROM was first issued in 2011 and updated last in 2016. The latest version may be downloaded from: ftp://ftp.ciemat.es/pub/CROM/CROM_8/. [8]

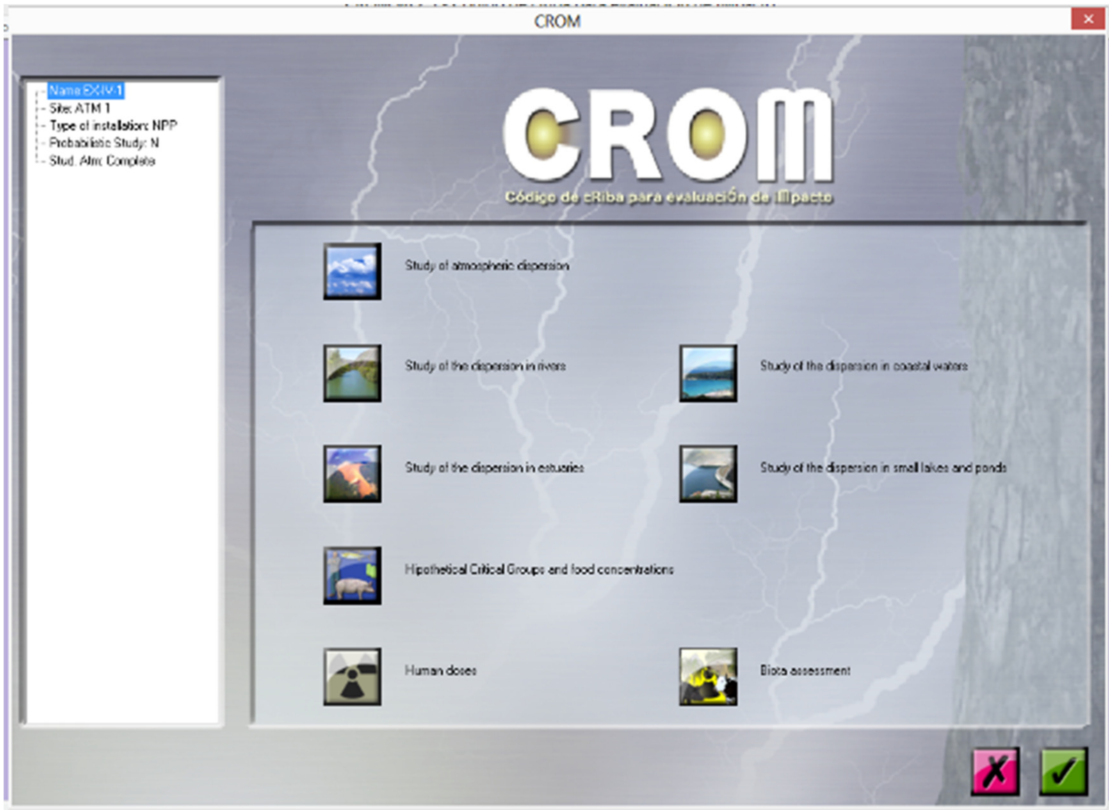


Figure 7: CROM.

2.8.1 CROM Exposure Scenarios and Pathways

CROM can be used for residence and farm land uses. It can assess the release of radionuclides to the environment for eight scenarios: Atmospheric dispersion, Dispersion in rivers, Dispersion in estuaries, Dispersion in coastal waters, Dispersion in small lakes and ponds, Hypothetical critical groups and food concentrations, Human doses, and Biota assessment. Radiation dose can be calculated for irradiation from: air submersion, ground deposition, water immersion while swimming, shore sediments, intake due to food ingestion, intake due to water ingestion, and incorporation due to inhalation.

2.9 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 [9]; however, an English language version of the WISMUT model User Guide was provided for this analysis.

2.9.1 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. [9]

III. DEFAULT INPUT PARAMETERS

Radiation risk assessment models have default input parameters for relevant exposure scenarios and pathways that can be used for the initial assessment. The default input parameters are an important part of the models that may be used for generic assessment and when site-specific data is not available. Sometimes, acquiring site-specific data is costly. It requires field measurements and public surveys, which require more time and effort. Certain parameters are not readily obtained, and risk assessors need to apply these parameters to run the models, so they would use the default input parameters. Default parameters in models, issued and/or recommended by regulatory agencies, usually provide users with the ability to run a model that will result in concentrations that should be suitable for regulatory compliance or screening purposes from risk or dose limits for a given land use. If the default parameters in a model are conservative, then the regulator may allow the use of some site-specific parameters to replace defaults when sufficiently justified.

The default input parameters used by the models have different numerical values. There are a number of considerations that can lead to this variability, such as inter individual variability (age, sex, and human behavior and habits, where intake can vary between different groups of humans), spatial variability, and temporal variability [10]. In addition, regulatory scheme can affect the values of some parameters. For example, the EPA uses the consumption rate for the Reasonable Maximum Exposed (RME) for an individual, which is a mixture of 50^{th} and 95^{th} or 90^{th} percentile parameters for an upper bound exposure, while the US Nuclear Regulatory Commission (NRC) uses the parameters for average group member of the critical group. NRC tends to select unrestricted land use. EPA uses the reasonably anticipated land use, which is usually a restricted land use with less exposure.

The variability of the default input parameters would influence the output of the assessment. Also, some models have parameters that are not considered by other models. The following section is an overview of the default input parameters of the models. This overview shows the variability of selected parameters. Parameters have been converted to be in the same units. For PRG/DCC, the unit for consumption rate for food is per day; the consumption is converted to a year based on 350 days/yr assumed in the calculators for the farmer and resident scenarios. Same names and categories of parameters from each model have been listed in the tables below and graphed for better presentation. The default input parameters for PRG/DCC, RESRAD-ONSITE, RCLEA and CROM were obtained from the models, user's manuals, and the main references used to develop the models. NOMALYSA has no user's manual, so the parameters were taken directly from the model. Parameters for RaSoRS were obtained from the Excel spreadsheet. WISMUT is not available in English but has a user's manual in English, which was used to find the related parameters. NCRP report 129 was the source of the NCRP default parameters that are listed in this document. Appendices at the end of this document list the original default input parameters from sources before conversions to similar units.

3.1 Physiological Factors

Physiological factors in this document focus on sex, age and breathing rate. The only model that differentiates in the sex of receptors is RCLEA. For age, all models have parameters for both children and adults except RESRAD-ONSITE, RaSoRS and NCRP. These three models have only default input parameters for adult. NCRP has only one parameter for children, which is the soil consumption rate. Breathing rate is usually the most important factor for determining the inhalation dose. Adults have higher breathing rates than children in a given context. The breathing rates are much higher for adults based on the occupation. For instance, construction worker has a higher breathing rate than farmer. RESRAD-ONSITE has breathing rates for four scenarios (Resident Farmer, Suburban Resident, Industrial Worker, Recreationist). NORMALYSA and CROM have two parameters for breathing rate (infant/child and adult). RCLEA has numerous default input parameters for breathing rate for active and passive breathing for different ages and sexes. RCLEA contains a total of 12 default input parameters for breathing rates. The male adults have the highest active breathing rate compared to female adults and male child/infants. RaSoRS has two different adult breathing rate parameters for indoor and outdoor; it is the only model that differentiates between indoor and outdoor breathing rate. WISUMT usually contains seven parameters for breathing rate that increase with age. NCRP has outdoor breathing rates for all NCRP land uses and indoor breathing rates only for heavily vegetated rural, sparsely vegetated rural, and suburban land uses.

Table 1: Physiological Factors.

Model	Sex	Age	Breathing Rates (m^3/h)			
PRG, DCC, RSL	N/A	Child	0.41	Resident, Recreator, Farmer		
		Adult	0.83	Resident, Recreator, Farmer		
			2.5	Construction & Composite Worker		
RESRAD (ON-SITE)	N/A	Adult	Resident Farmer	Suburban Resident	Industrial Worker	Recreationist
			0.95	0.95	1.3	1.6
NORMALYSA	N/A	Infant	0.92			
		Child	0.64			
RCLEA*			Active	Passive		
	Male	Infant	0.339	0.124		
		Child	1.103	0.404		
		Adult	1.456	0.485		
	Female	Infant	0.32	0.117		
		Child	1.1	0.403		
		Adult	1.234	0.411		
CROM	N/A	Adult	0.95			
		Infant	0.16			
		0-1	0.16			
		1--2	0.22			
		2--7	0.36			
		7--12	0.64			
		12--17	0.84			
		>17	0.95			
RaSoRS	N/A	Adult		Indoor on site	Outdoor on site	
			Residential	0.63	1.4	
			Commercial	1.4	1.4	
WISMUT	N/A	≤ 1	0.12			
		1 - 2	0.22			
		2 - 7	0.36			
		7 - 12	0.64			
		12 -17	0.84			
		> 17	0.93			
		Worker	1.2			
NCRP	N/A	Adult	Land-use	Outdoor	Indoor	
			Agricultural	1.4	-	
			Heavily Vegetated Pasture	1.4	-	
			Sparsely vegetated pasture	1.4	-	
			Heavily Vegetated rural	1.25	0.83	
			Sparsely Vegetated rural	1.25	0.83	
			Suburban	1.04	0.83	
			Construction, etc.	1.4	-	

* Note that the breathing rates are consistent with the CLEA methodology. [11]

3.2 Occupancy Factors

Occupancy factors are the time spent by an individual on a contaminated site. It is different for different scenarios and land uses. Exposure should be corrected to reflect the true fraction of time spent on site. Most of the models use a fraction of the time for calculations. PRG and DCC calculators use exposure frequency (days/yr), exposure duration (years) and exposure time (hour/day). RESRAD-ONSITE, NORMALYSA, RCLEA and CROM use fraction of time spent indoors and outdoors. RCLEA uses another dimension for the occupancy factors, which are active or passive occupancy. NCRP and RaSoRS use percentage to represent occupancy factor. WISUMT use number of hours per year to represent the occupancy factors.

Table 2: Occupancy Factors.

PRG & DCC (RSL&RML for exposure frequency and duration)	**Resident**	**Farmer**	**Construction Worker**	**Indoor Worker**	**Outdoor Worker**	**Composite Worker**	**Recreator**
Exposure Frequency (days/yr)	350	350	250	250	225	250	Site-specific
Exposure Duration (years)	General: 26 Adult: 20 Child: 6	General: 40 Adult: 34 Child: 6	1 yr	25	25	25	Site-specific
Exposure Time - indoor (hours/day)	16.4	10	-	-	-	-	Site-specific
Exposure Time - outdoor (hours/day)	1.75	12.16	-	-	-	-	Site-specific
Exposure Time (hours/day)	24	24	8	8	8	8	Site-specific
Exposure Time -away (hours/day)	-	1.83	-	-	-	-	Site-specific

RESRAD-ONSITE	Fraction of time spent indoor	6.55E-01
	Fraction of time spent outdoor	2.5E-01

NORMALYSA		All groups
	Fraction of time spent outdoor	0.25

CROM	**External Exposure**	**Adult**		**Infant**	
		(Hour/yr)	Fraction	(Hour/yr)	Fraction
	Surface contaminated owing to air deposition	8760	1	8760	1
	Working /playing over contaminated sediment	1600	0.18	1000	0.12
	Submersion in air	8760	1	8760	1
	Garden and ground exposure from irrigation	500	0.06	500	0.06

RCLEA		**Adult**		**Child**		**Infant**	
	Fraction of time spent:	Active	Passive	Active	Passive	Active	Passive
	Residential with Home-Grown Produce, indoor	0.125	0.708	0.083	0.667	0.125	0.750
	Residential with Home-Grown Produce, outdoor	37.96	0.063	0.083	0	0.083	0.042
	Residential without Home-Grown Produce, indoor	0.125	0.708	0.083	0.667	0.125	0.750
	Residential without Home-Grown Produce, outdoor	37.96	0.063	0.083	0	0.083	0.042
	Allotments, indoor	0.125	0.708	0.083	0.667	0.125	0.750
	Allotments, outdoor	34.675	0.047	0.012	0.012	13.14	0.018
	Commercial/Industrial, indoor	0.052	0.144	-	-	-	-
	Commercial/Industrial, outdoor	0.013	0.006	-	-	-	-

-Occupancy Assumptions for the Residential Land Use; **Note that Infants adopt 1 to 2 year old characteristics from CLEA, Children adopt the 10 to 11 year old characteristics and Adults adopt the 59 to 70 year old characteristics to maximize the exposure duration. Values based on CLR 10 Tables 4.3 and 4.4. [11]**

-Occupancy Assumptions for the Allotment Land Use; **Note that Infants adopt 1 to 2 year old characteristics from CLEA, Children adopt the 10 to 11 year old characteristics and Adults adopt the 59 to 70 year old characteristics to maximize the exposure duration. Values based on CLR 10 Tables 4.8, 4.9 and 4.10. [11]**

-Occupancy Assumptions for the Commercial/Industrial Land Use; **Values based on CLR 10 Table 4.13, which are presented for female workers aged 16 to 59. [11]**

RaSoRS		Residential	Commercial
	Fraction of time spent indoors on site:	68%	18%
	Fraction of time spent outdoors on site:	8%	5%

NCRP	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

WISMUT	Exposure site	Ref. person	Exposure time (hours)			
	1. Indoors:	Worker	Up to 2000			
		Member of the public	7000			
	2. Outdoors:	Worker	Up to 2000			
		Member of the public	Up to 2000			
	Where the following values result for a member of the public, depending on local conditions, from:					
	2.1 uncultivated mine dumps or uncultivated areas, contaminated by mining residues	≤ 1 yr	1 - 2 yr	2 - 7 yr	7 - 12 yr	12 -17 yr
		0	100	250	250	250
	2.2 garden areas	Member of the public	1000			
	2.3 traffic areas	Member of the public	1000			
	2.4 parks and recreation centers, children's play areas	Member of the public	1000			

3.3 Dietary Factors for Human Food Consumption

3.3.1 Drinking Water Intake

The consumption of contaminated water is a significant radionuclide ingestion pathway that contributes to internal exposure. This contribution should be considered in the derivation of the dose from ingestion. The external exposure from contaminated water is mostly negligible, compared with internal exposure. Source and amount of water consumed plays an important role in calculation of internal dose. The source of water can be groundwater or surface water or both. Individuals on site could consume 100%, or a fraction thereof, contaminated water. Some of the models use a value for drinking water consumption that assumes the water is completely contaminated with radionuclides, such as WISMUT. A fraction of contaminated water can be used for PRG/ DCC or RESRAD-ONSITE. Some other models do not use a fraction contamination parameter for drinking water, such as RCLEA and NCRP. The consideration for a resident that has access to water from the uncontaminated municipal water should be different from a farmer using well water on contaminated sites. The fraction and the amount of water consumed should reflect these considerations.

The default value of the amount of drinking water consumed is usually obtained from public surveys. The concentration of activity in drinking water assumed in the models is usually overestimated, because water can be filtered and treated before consumption. The coagulation and filtration of water could reduce the concentration of radionuclides and in turn reduce the internal exposure. [12]

Table 3 lists drinking water intake in units of L/yr for the models. PRG and DCC calculators use different scenarios, such as farmer, resident, and recreator, for both adult and child. Farmer and resident consume the same amount of tap water per year. Adults in the farmer and resident scenarios have higher tap water consumption per year compared to child for the same scenarios. The farmer/resident adult ingests 875 L/yr, and the child ingests 273 L/yr (based on 350 d/yr). In the case of adult and child recreator, the intake of surface water is 0.071 L/hr and 0.12 L/yr, respectively. The adult is more careful of ingesting the surface water compared to the child. For RESRAD-ONSITE, individuals ingest an equal amount of water yearly. People, irrespective of age and occupation, have equal chances of being exposed to contaminated water. In RESRAD-ONSITE, a fraction of water can be used if the drinking water is not totally contaminated. In NORMALYSA, the default consumption stands at 375 L/yr for adult and lactating mother, while the water intake for child/infant is 76 L/yr. In the CROM model, adult water intake is 600 L/yr while infant is 260 L/yr. RaSoRS only works for adults. In this model, the water ingestion per year stands at 700 L/yr. In WISMUT, water consumption increases with age; however, the overall consumption for adults in WISMUT is lower than all other models in the table.

Table 3: Drinking water intake (L/yr).

PRG, DCC and RSL	Farmer/ Resident, Adult	875	Tap water ingestion
	Farmer/ Resident, Child	273	Tap water ingestion
	Recreator, Adult*	0.071 (L/hr)	Surface water
	Recreator, Child*	0.12 (L/hr)	Surface water
RESRAD-ONSITE	Adult	510	
NORMALYSA	Adult and Lactating mother	375	
	Child, Infant	76	
CROM	Adult	600	Water and beverages
	Infant	260	Water and beverages
RaSoRS	Adult	700	
WISMUT	Reference person		
	≤ 1 yr	55	
	1 - 2 yr	100	
	2 - 7 yr	100	
	7 - 12 yr	150	
	12 -17 yr	200	
	> 17 yr	350	

* Recreator scenario in PRG/DCC calculators is site-specific with no assumed default occupancy factors, such as how many hr/day and days/yr.

3.3.2 Fruits, Vegetables and Grains Consumption Rates

Fruits, vegetables and grains can uptake radionuclides from contaminated sites by root uptake from contaminated soil and contaminated irrigation water or leaves uptake from the deposition of contaminated dust and contaminated irrigation water. Consumption of contaminated food is a major ingestion pathway and has a significant impact on the result of the assessment. Default input parameters of food consumption rate depend on the behavioral characteristics of potential receptors, age, sex and harvesting season. The parameters can be obtained from public dietary surveys.

Most of the radiation risk assessment models make a difference between children and adults, when calculating the consumption rates of fruits, vegetables, and grains. This is not done by RESRAD-ONSITE and RaSoRS. Also, different scenarios have different consumption rates. For example, the farmer scenario consumes more contaminated food than the industrial scenario. The fraction of the fruits, vegetables, and grains that are contaminated by radionuclides from the contaminated zone is determined by the fraction raised locally and the area of the contaminated zone.

The category of the consumption also differs between models. Some models provide the number of crops; other models use a general category. More types of plants provide more options and reduce uncertainties. In Table 4, the consumption of fruits, vegetables, and grains is presented in kilograms per year. Figure 8 shows the number crop types that are included in each model. DCC and PRG have 24 different crops. For each of these 24 crops, the PRG and DCC have Fresh Weight (FW) consumption rates as a default, but users can click a button for Cooked Weight (CW) consumption rates, which are generally more appropriate for Americans and which should be selected if users have determined their site does not have a sensitive subpopulation with higher than normal intakes of a particular crop. Adults and children have different consumption rates depending on crops. From the table, the consumptions by adults are higher compared to that of children. Lifestyle contributes to different rates of crop consumption. For example, a farmer adult consumes more apples than a resident adult; however, the amount of berry consumed is equal for both farmer and resident adult. In some cases, the amount consumed is higher for the resident adult as compared to farmer adult. For example, the resident adult consumption of carrots is greater than farmer adult. RESRAD-ONSITE has only two main classifications: leafy vegetable and fruit and vegetable and grains. In NORMALYSA, crops are classified as cereals, leafy vegetables, legumes, roots, berries, mushrooms, garden food and fruits. The main consideration here is age. Adults consume more of the crops than children and infants; however, there is a scenario where adults consume less than children. For example, children consume an average of 40 kg/yr of roots, and adults consume an average of 39 kg/yr. RCLEA uses different dimensions for food consumption rates. The food consumption rate is expressed as kg of fresh weight of crops per kg of the body weight of the individual per year, (kg (fw)/kg (bw)/yr). Body weights for male/female adult, child, and infant are provided in RCLEA. In Table 4, the values of fruit and vegetables consumption rates are converted to kg/yr by multiplying the body weight (kg) for each individual by the value of the consumption (kg (fw)/kg (bw)/yr). RCLEA indicates increase in consumption as the age increases. CROM put the consumption rate of fruit and vegetables at 410 kg/yr and 150 kg/yr for adults and infants, respectively. RaSoRS indicates that adults consume an average 17 kg/yr. WISMUT content in various crops increases as the age increases except for fresh fruit, fruit products, and juice, where adults >17 consume less than 1 – 17 year-olds. NCRP has a combined consumption rate of 300 kg/yr for vegetables, fruits, roots, and grains.

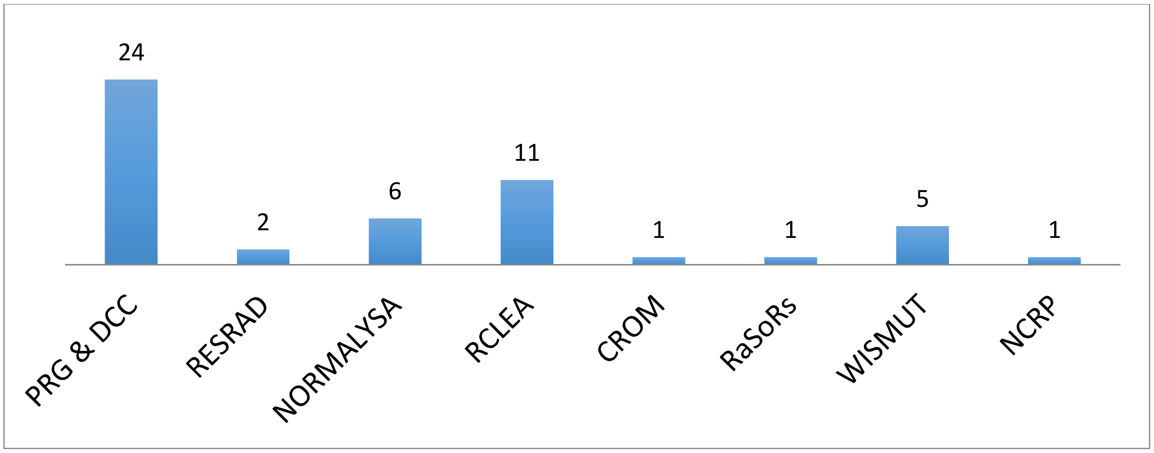


Figure 8: Number of crop types included in each model.

Table 4: Fruits, vegetables and grains consumption rates (kg/yr).

	Crop	**Resident Adult**		**Resident Child**		**Farmer Adult**		**Farmer Child**	
		FW	CW	FW	CW	FW	CW	FW	CW
PRG & DCC (yr=350 days)	Apple	25.8	13.4	25.3	13.1	29.6	15.4	29.0	15.1
	Citrus	108.3	56.1	67.9	35.2	108.3	56.1	68.0	35.2
	Berry	12.4	6.4	8.4	4.3	12.4	6.4	8.4	4.3
	Peach	40.5	21.0	39.0	20.2	36.1	18.7	34.8	18.0
	Pear	18.2	9.4	23.3	12.1	21.0	10.9	26.9	14.0
	Strawberry	14.2	7.4	8.9	4.6	14.2	7.4	8.9	4.6
	Asparagus	13.8	9.4	4.2	2.9	13.8	9.4	4.2	2.9
	Beet	11.9	8.1	1.4	0.9	11.9	8.1	1.4	0.9
	Broccoli	11.2	7.7	4.6	3.1	12.4	8.4	5.0	3.5
	Cabbage	32.2	22.0	4.3	2.9	30.0	20.5	4.0	2.7
	Carrot	9.6	6.5	5.2	3.6	8.5	5.8	4.7	3.2
	Corn	20.9	14.3	8.3	5.7	28.7	19.6	11.4	7.8
	Cucumber	28.8	19.7	8.9	6.1	19.2	13.1	5.9	4.0
	Lettuce	13.1	9.0	1.5	1.0	13.1	9.0	1.5	1.0
	Lima Bean	11.8	8.1	2.3	1.6	11.8	8.1	2.3	1.6
	Okra	10.6	7.2	1.9	1.3	10.6	7.2	1.9	1.3
	Onion	7.6	5.2	2.0	1.4	9.5	6.5	2.5	1.7
	Pea	12.4	8.5	11.2	7.7	11.1	7.6	10.0	6.9
	Pumpkin	22.7	15.5	15.8	10.8	22.7	15.5	15.8	10.8
	Snap Bean	18.9	12.9	9.6	6.5	19.0	13.0	9.6	6.6
	Tomato	28.1	19.2	10.4	7.1	33.0	22.5	12.2	8.3
	White Potato	44.7	30.6	18.1	12.4	49.6	33.9	20.1	13.7
	Rice	-	25.6	-	10.1	-	31.0	-	12.2
	Cereal Grain	-	26.6	-	13.3	-	32.2	-	16.1

RESRAD-ONSITE	Leafy vegetable	14
	Fruit, Vegetable and Grains	160

	Crop	Adult	Child	Infant
NORMALYSA	Cereals	52.04	53.69	64.92
	Leafy Vegetables	21.30	6.44	5.98
	Legume	2.19	0.73	0.73
	Roots	39.77	40.10	28.59
	Berries	6.64	3.33	3.33
	Mushrooms	0.45	0.15	0.15
	Garden Food			
	Fruits	3.52	1.77	3.23
	Garden Berries	0.78	0.78	0.78
	Leafy Vegetables	21.30	6.44	5.98
	Legumes	2.19	0.73	0.73
	Roots	39.77	40.10	28.59

	Crop	Adult		Child	Infant
		male	female	male/female	male/female
RCLEA*	Brussels Sprouts	20.74	17.41	9.25	5.17
	Cabbage	19.85	16.66	8.51	5.94
	Carrot	19.20	16.12	13.32	7.15
	Leafy Salads	14.50	12.17	7.03	4.40
	Onion (shallots and leeks)	13.04	10.95	8.51	3.63
	Potato	100.44	84.32	76.96	30.03

*Note that these values in RCLEA represent the 95th percentile of the CLEA distributions and are derived from Table 6.3 of the Contaminated Land Report-10 (CLR 10). [11]

		Adult	Infant
CROM	Fruits, vegetables and grains	410	150

		Adult
RaSoRS	Homegrown crop	17.136

	Crop	Reference Person					
		≤ 1 yr	1 - 2 yr	2 - 7 yr	7 - 12 yr	12 -17 yr	> 17 yr
WISMUT	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

		Adult
NCRP	Vegetables, Fruits, roots, grains	300

3.3.3 Milk/ Dairy and Meat Consumption Rates

People living in rural areas often raise livestock to provide most of their meat and milk. When livestock graze on contaminated areas, the radionuclides in vegetation, soil, water and air transfer into their system. Consequently, the produced meat and milk from these animals would be contaminated. The radionuclide intakes by animals depends on the type of animal, age, growth rate of the animal, and grazing season [3]. Meat and milk consumption contributes to the exposure from ingestion pathways. The contribution is different based on the scenario. For example, industrial workers usually do not consume any contaminated meat or milk, but the farmer may consume a large fraction of his daily need of milk and meat from the livestock raised on a contaminated site.

Table 5 shows milk/dairy consumption in unit L/yr. PRG and DCC calculators have dairy consumption rates only for the adult and child farmer scenario. The dairy consumption rate includes milk, cheese, ice cream and yogurt. The PRG and DCC dairy consumption rates are in units of g/day. The density of milk (1.03 kg/L) was used to convert the unit to L/yr. RESRAD-ONSITE put both the child and adult at equal rates of 92 L/yr. NORMALYSA indicates consumption of cow products decreases as age increases. With CROM, an adult consumes 250 L/yr, while infants consume 300 L/yr. WISMUT milk consumption increases with age until age 17, then the consumption decreases. RCLEA and RaSoRS have no parameters for milk consumption rates. The highest milk consumption rate parameter is assumed by NCRP at 200 L/yr.

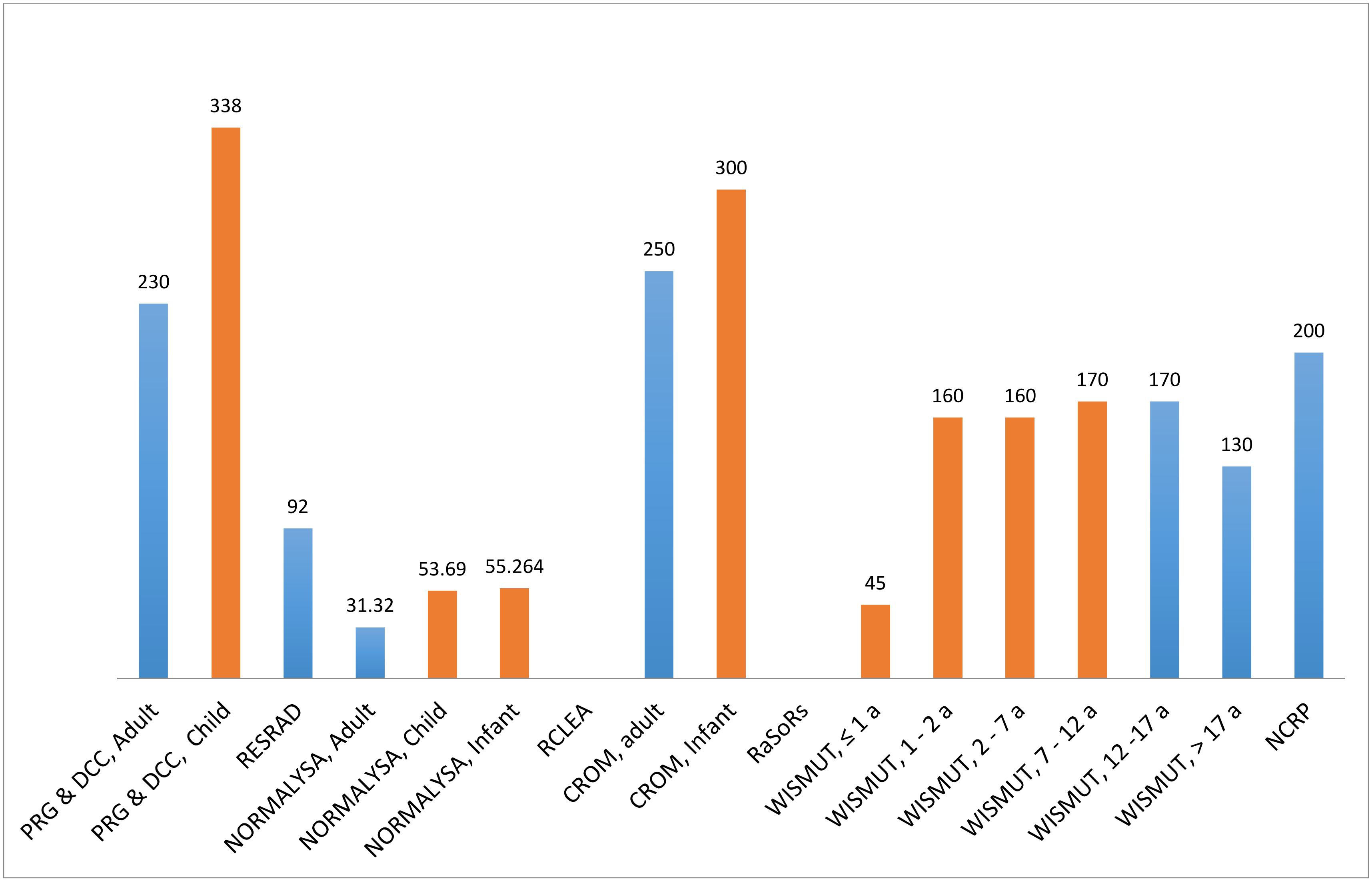


Figure 9: Milk/ Dairy consumption rates (L/yr).

Table 5: Milk/ Dairy consumption rates (L/yr).

PRG & DCC	Adult	236.7	Farmer Dairy Ingestion Rate
	Child	348.2	Farmer Dairy Ingestion Rate
RESRAD-ONSITE	Adult	92	
NORMALYSA	Adult	31.32	Cow
	Child	53.69	Cow
	Infant	55.26	Cow
CROM	Adult	250	
	Infant	300	
WISMUT	≤ 1 yr	45	
	1 - 2 yr	160	
	2 - 7 yr	160	
	7 - 12 yr	170	
	12 -17 yr	170	
	> 17 yr	130	
NCRP	Adult	200	

Table 6 considers meat and poultry consumption rates in kilograms per year. PRG and DCC have parameters for only the farmer scenario. The consumption includes beef, poultry, swine, and egg for adult and child. According to PRG and DCC parameters, farmers consume beef, poultry, swine and egg in descending order, where an adult consumes more than a child. RESRAD-ONSITE put one value for meat consumption at 63 kg/yr. In NORMALYSA, the default input parameters for meat consumption (beef, sheep, moose, roe dear, and wild boar) assume a child consumes more meat than an adult or an infant. WISMUT shows an increase in consumption as age increases. CROM and NCRP assume a 100 kg/yr meat consumption rate for adult, which is the highest value among the models.

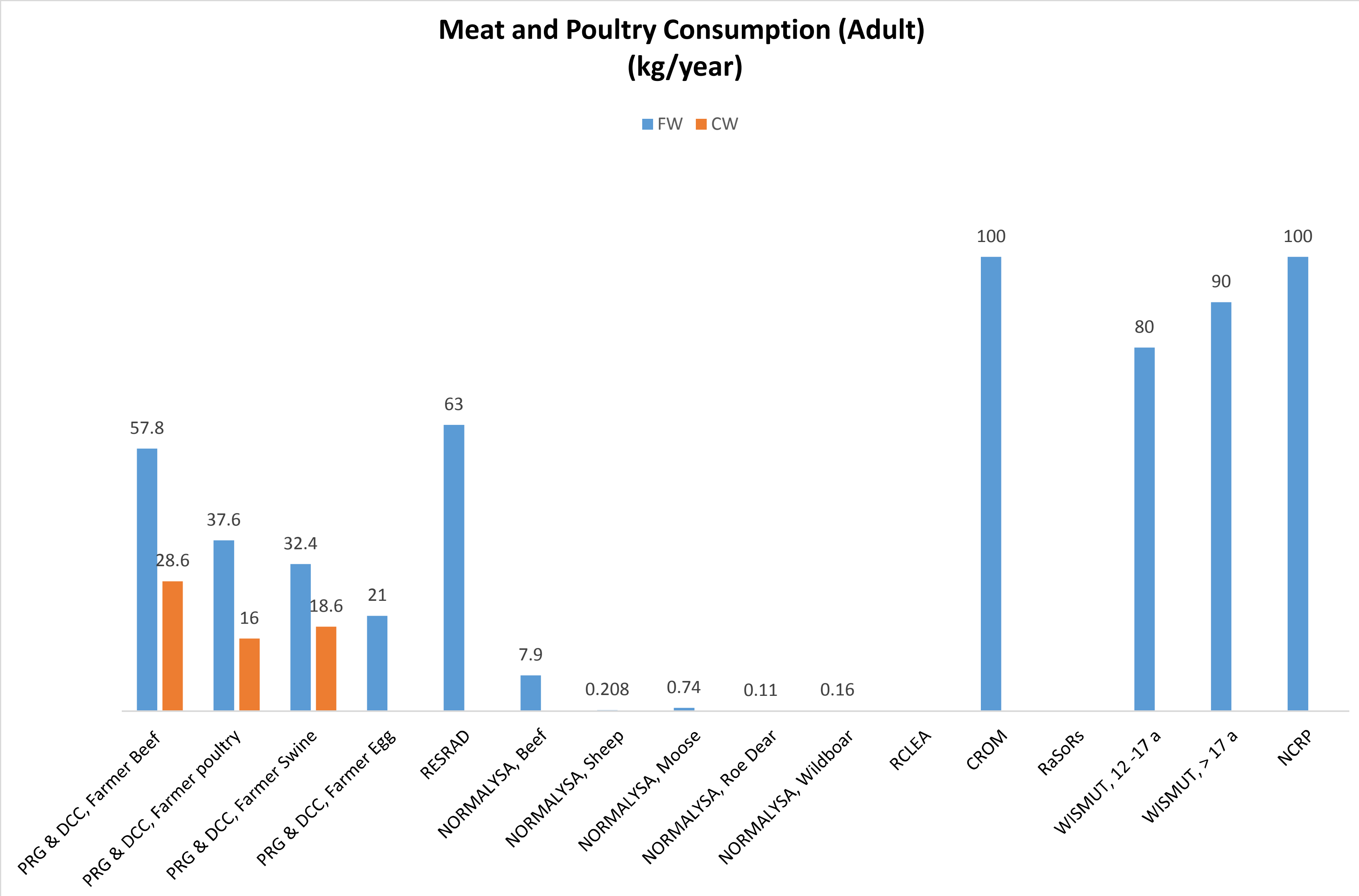


Figure 10: Meat and Poultry consumption rates for adult (kg/yr).

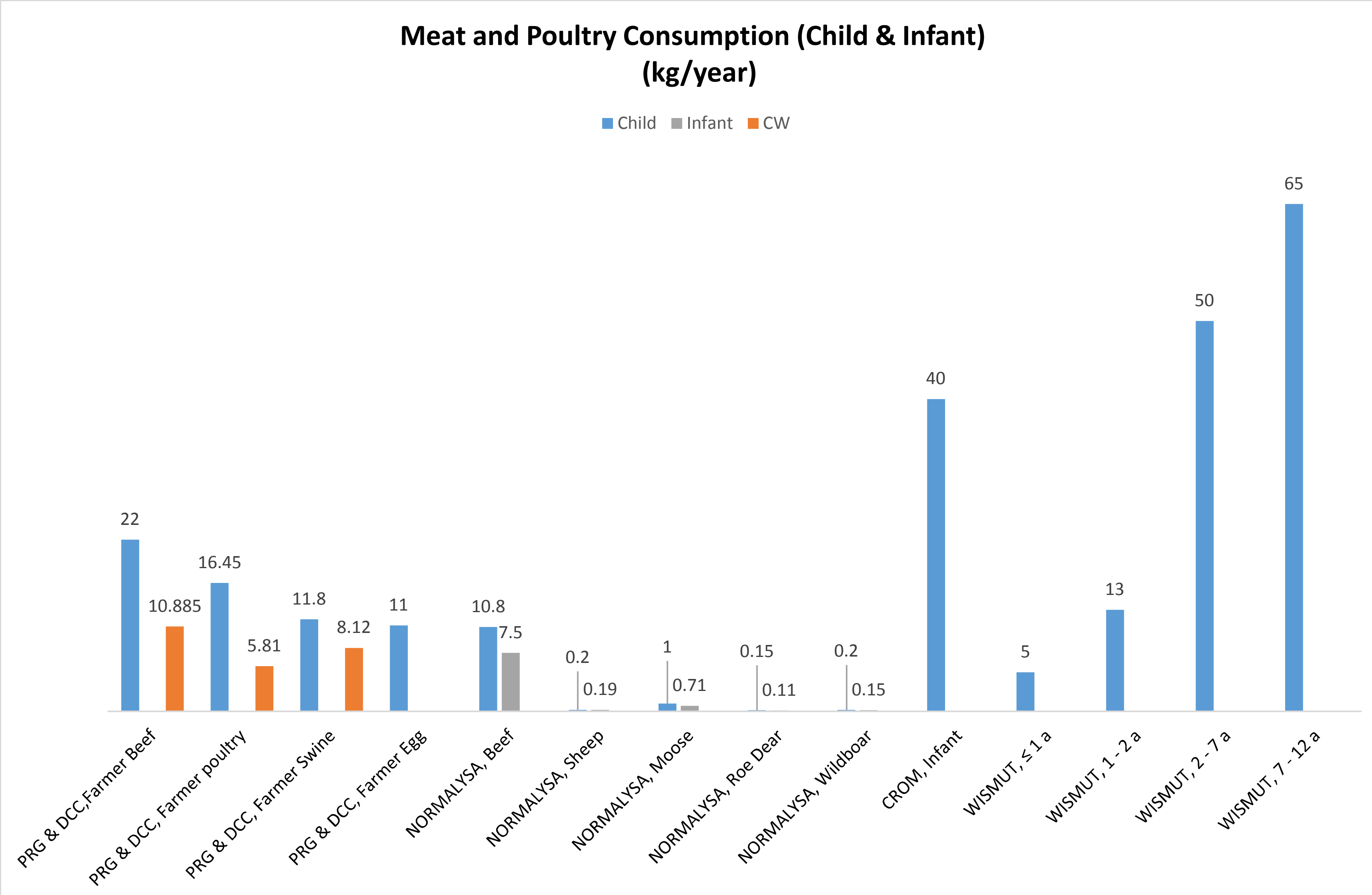


Figure 11: Meat and Poultry consumption (child & infant) (kg/yr).

Table 6: Meat and Poultry consumption rates (kg/yr).

	Animal	Farmer Child (FW)	Farmer Adult (FW)	Farmer Child (CW)	Farmer Adult (CW)
PRG & DCC	Beef	22.0	57.9	10.9	28.6
	Swine	11.8	32.4	5.8	16.0
	Poultry	16.4	37.6	8.1	18.6
	Egg	11.1	20.9	-	-

		Adult
RESRAD-ONSITE	Meat and Poultry (Unspecified)	63

	Animal	Adult	Child	Infant
NORMALYSA	Beef	7.9	10.8	7.5
	Sheep	0.21	0.21	0.20
	Moose	0.74	1.02	0.71
	Roe Dear	0.11	0.16	0.11
	Wild boar	0.16	0.22	0.15

		Adult	Infant
CROM	Meat (Unspecified)	100	40

		≤ 1 yr	**5**
WISMUT	Meat (Unspecified)	1 - 2 yr	13
		2 - 7 yr	50
		7 - 12 yr	65
		12 -17 yr	80
		> 17 yr	90

		Adult
NCRP	Meat (Unspecified)	100

3.3.4 Fish & Seafood Consumption Rates

Consumption of fish and seafood / aquatic food from a pond that has been contaminated by radionuclides is another important ingestion pathway that is considered when assessing a contaminated site. Radionuclides in water and sediment transfer to aquatic biota and then to humans. The consumption of these species contributes to the internal exposure to humans.

Table 7 shows fish and seafood consumption rates in units of kg/yr. PRG & DCC calculators have consumption rates for the adult and child farmer scenarios. The default input parameters for fish consumption are fresh weight (FW) at values of 291.13 kg/yr for adult and 20.09 kg/yr for child. This amount of fish is much higher than the fish consumption rate in the other models. Fish, Crustacea and Molluscs are the categories available in RESRAD-ONSITE. NORMALYSA divides the seafood consumption as marine and freshwater consumption. Both categories have subcategories of Cray Fish, Fish, and Mussels with same ingestion rate for adult, child and infant. CROM categorizes the consumption rate of aquatic species as freshwater fish, marine fish and marine shellfish. WISMUT has consumption for all six age ranges in the model. The consumption rates increase with age. RCLEA, RaSoRS and NCRP have no parameters for fish and seafood consumption rates.

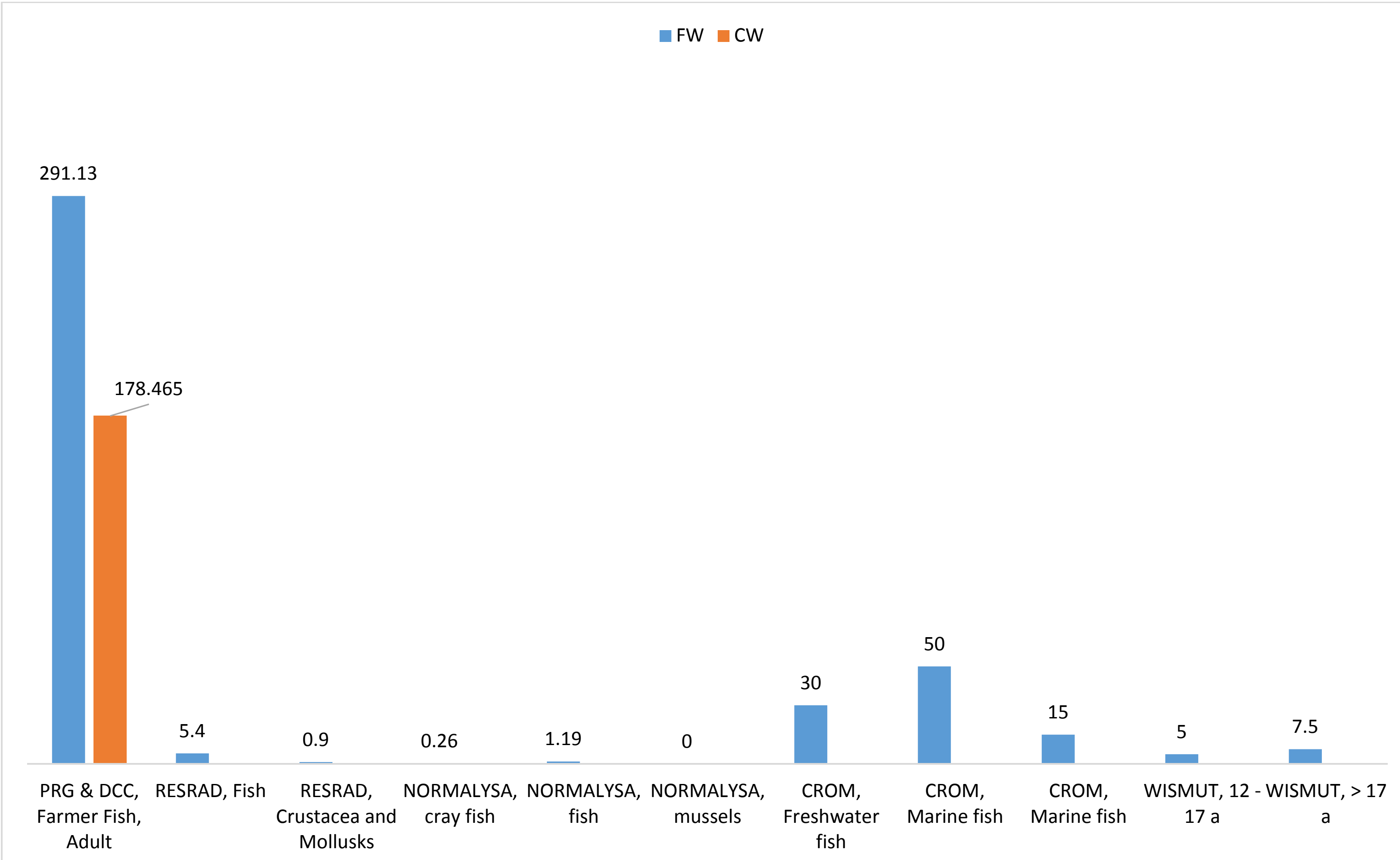


Figure 12: Fish & Seafood consumption for adult.

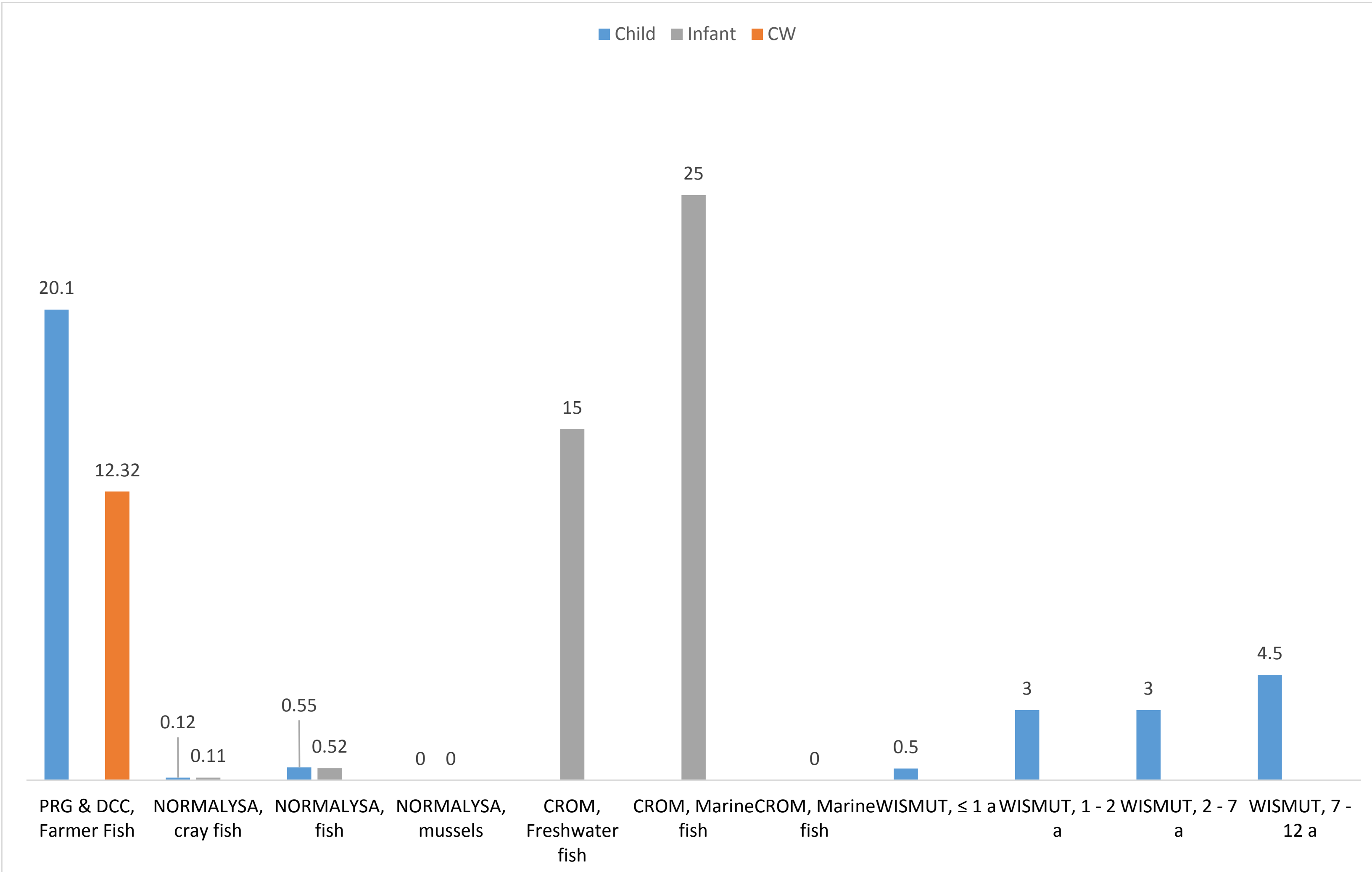


Figure 13: Fish & Seafood consumption for infant and child.

Table 7: Fish & Seafood consumption rates (kg/yr).

PRG/DCC		**Farmer Child (FW)**	**Farmer Adult (FW)**	**Farmer Child (CW)**	**Farmer Adult (CW)**
	Fish	20.1	291.1	12.3	178.5
RESRAD-ONSITE	Fish			5.4	
	Crustacea and Mollusks			0.9	
NORMALYSA	Marine/ Freshwater			Adult	Child	Infant
	Cray fish			0.26	0.12	0.11
	Fish			1.19	0.55	0.51
	Mussels			0	0	0
CROM				Adult	Infant	
	Freshwater fish			30	15	
	Marine fish			50	25	
	Marine shellfish			15	0	
WISMUT	≤ 1 yr			0.5		
	1 - 2 yr			3		
	2 - 7 yr			3		
	7 - 12 yr			4.5		
	12 -17 yr			5		
	> 17 yr			7.5		

3.4 Animal Consumption Rates

Table 9 presents the animal consumption rates of fodder, soil and water in kg/yr. The PRG and DCC calculators contain default input parameters for 11 types of animals (Beef, Dairy, Goat, Goat Milk, Chicken, Duck, Turkey, Goose, Sheep, Sheep Milk, and Swine). The animals that feed mostly on fodder and water the most are the beef or dairy animals, while the least is the chicken. The highest for those consuming soil is the sheep milk, while the least is chicken. RESRAD-ONSITE has animal consumption rate default input parameters for beef for meat and milk. Both consume the same amount of soil. Beef for meat consume more fodder and less water compared to beef for milk. NORMALYSA has parameters for the same categories as RESRAD-ONSITE, but Cow for meat consumes more fodder, soil and water compared to Cow for milk. CROM considers fodder and water consumption rates for large animals only; there is no classification of these large animals. For small animals, the default input parameter is one-tenth the consumption of that for large animals. WISMUT only provides parameters for Cattle (Beef). The soil consumption rate by cows in WISMUT agrees with RESRAD-ONSITE and PRG&DCC values at 182.5 kg/yr (Figure 14). NCRP has a fodder consumption rate for six animals (Milk cows, Beef cattle, Pigs, Calves, Lamb and Chicken). RCLEA and RaSoRS have no parameters for animal consumption rate. The following table presents animal consumption rates for each model.

Table 8: Summary of animal consumption rates in each model.

	Fodder	Soil	Water
PRG & DCC	yes	yes	yes
RESRAD-ONSITE	yes	yes	yes
NORMALYSA	yes	yes	yes
RCLEA	no	no	no
CROM	yes	no	yes
RaSoRS	no	no	no
WISMUT	yes	yes	yes
NCRP	yes	no	no

Table 9: Animal consumption rates (kg/yr).

	Animal	Fodder	Soil	Water (L/yr)
PRG & DCC	Beef	4,296.1	182.5	19,345.0
	Dairy	7,409.5	146.0	33,580.0
	Goat	463.6	84.0	1,390.7
	Goat Milk	580.4	105.9	3,193.8
	Chicken	73.0	8.0	146.0
	Duck	87.6	8.8	175.2
	Turkey	248.2	24.8	496.4
	Goose	120.5	12.0	240.9
	Sheep	638.8	116.8	1,916.3
	Sheep Milk	1,149.8	208.1	3,796.0
	Swine	1,715.5	135.1	4,161.0
RESRAD (ON-SITE)	Livestock (Beef) for meat	24,820.0	182.5	18,2500.0
	Livestock (Beef) for milk	20,075.0	182.5	58,400.0
NORMALYSA	Cow for meat	4,161.0	255.5	21,915.0
	Cow for milk	3,321.5	219.0	14,610.0
CROM	Large animal for milk	5,840.0	-	21,900.0
	Large animal for meat	4,380.0	-	14,600.0
	Small Animal such as goat and sheep, one tenth of these quantities should be used as a default			
WISMUT	Cattle	23,725.0	182.5	27,375.0
NCRP	Milk cows	5,840.0	-	-
	Beef cattle, game	2,920.0	-	-
	Pigs	876.0	-	-
	Calves	693.5	-	-
	Lamb	401.5	-	-
	Chicken	25.6	-	-

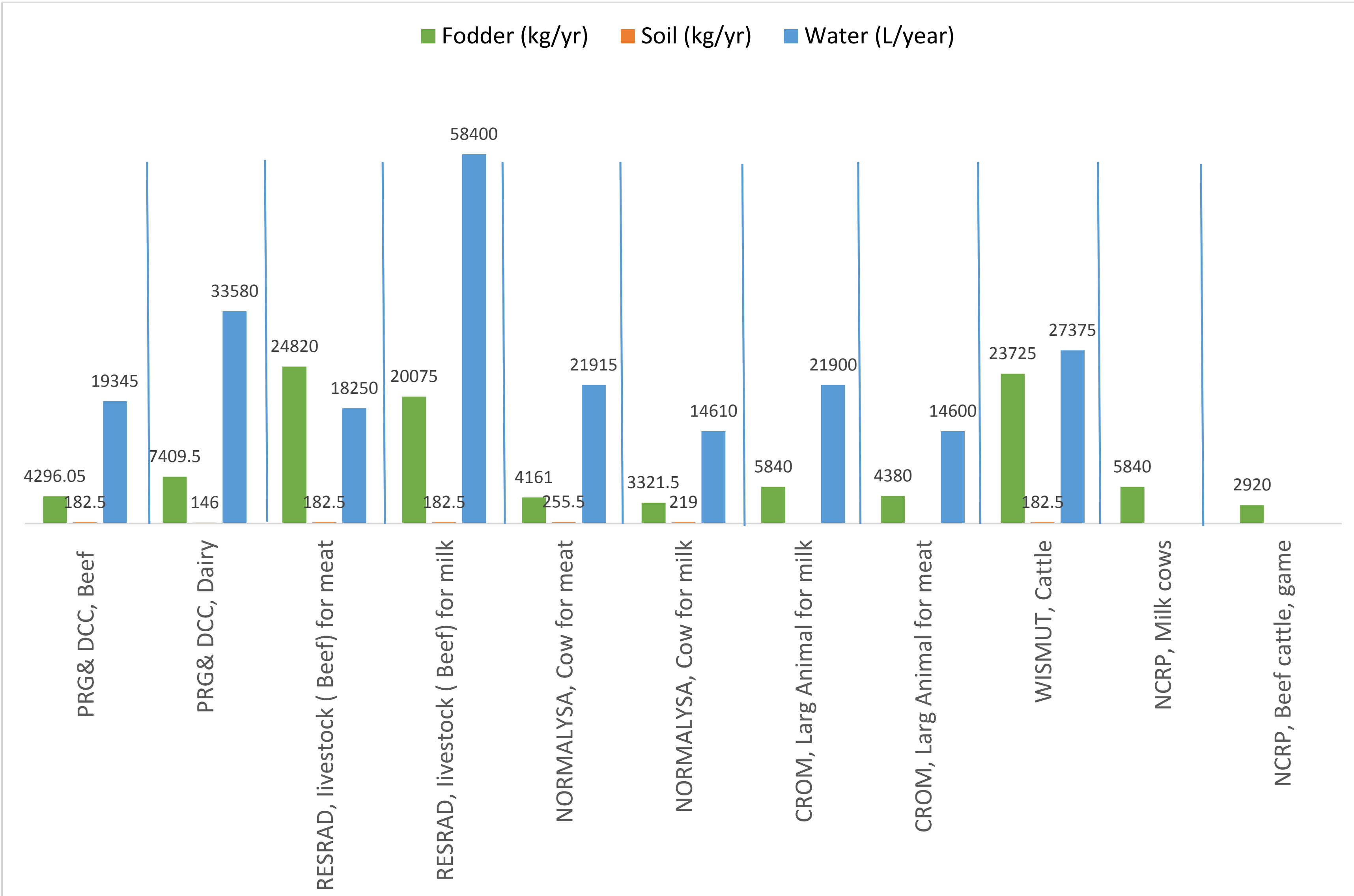


Figure 14: Fodder, soil and water consumption rates for Cattle.

3.5 Soil Consumption Rates:

The soil ingestion pathway is the direct ingestion of soil by individuals in a contaminated site. The amount of soil ingested and the concentration of radionuclides in soil are the factors that determine the dose from ingestion of soil. The soil ingestion pathway is a major pathway for infants/children, who are known to have significantly higher ingestion rates for non-food objects. [13]. Another aspect that determines the amount of consumption of soil is outdoor activities, where individuals are exposed to dust and soil more than indoor.

The soil consumption rates are presented in Table 10 in units of kg/yr. The soil consumption rates are almost equal for adult. PRG/DCC (Resident, Recreator, Farmer, Outdoor Worker, Composite), RESRAD-ONSITE, and NCRP (Agricultural, Sparsely Vegetated rural, Construction) use a soil consumption rate of 0.0365 kg/yr for a 365 day year. PRG/DCC, however, uses a year of 350 days for resident and farmer scenarios and 250 days for indoor worker, outdoor worker, composite and construction worker. By converting the units, the soil consumption rate will decrease. In general, most of the models use higher values for infant and child scenarios than adult. In PRG and DCC, the indoor worker consumes less soil compared to the construction worker, which is a normal result of the amount of soil/dust in the sounding environment. CROM has no soil consumption parameters; however, according to the main reference that was used to develop CROM, "The effect of radionuclide intake through inadvertent soil ingestion by humans or grazing animals is implicitly taken into account within the element specific values selected for the soil to plant uptake coefficient" (IAEA Reports Series No. 19, 2001) [14].

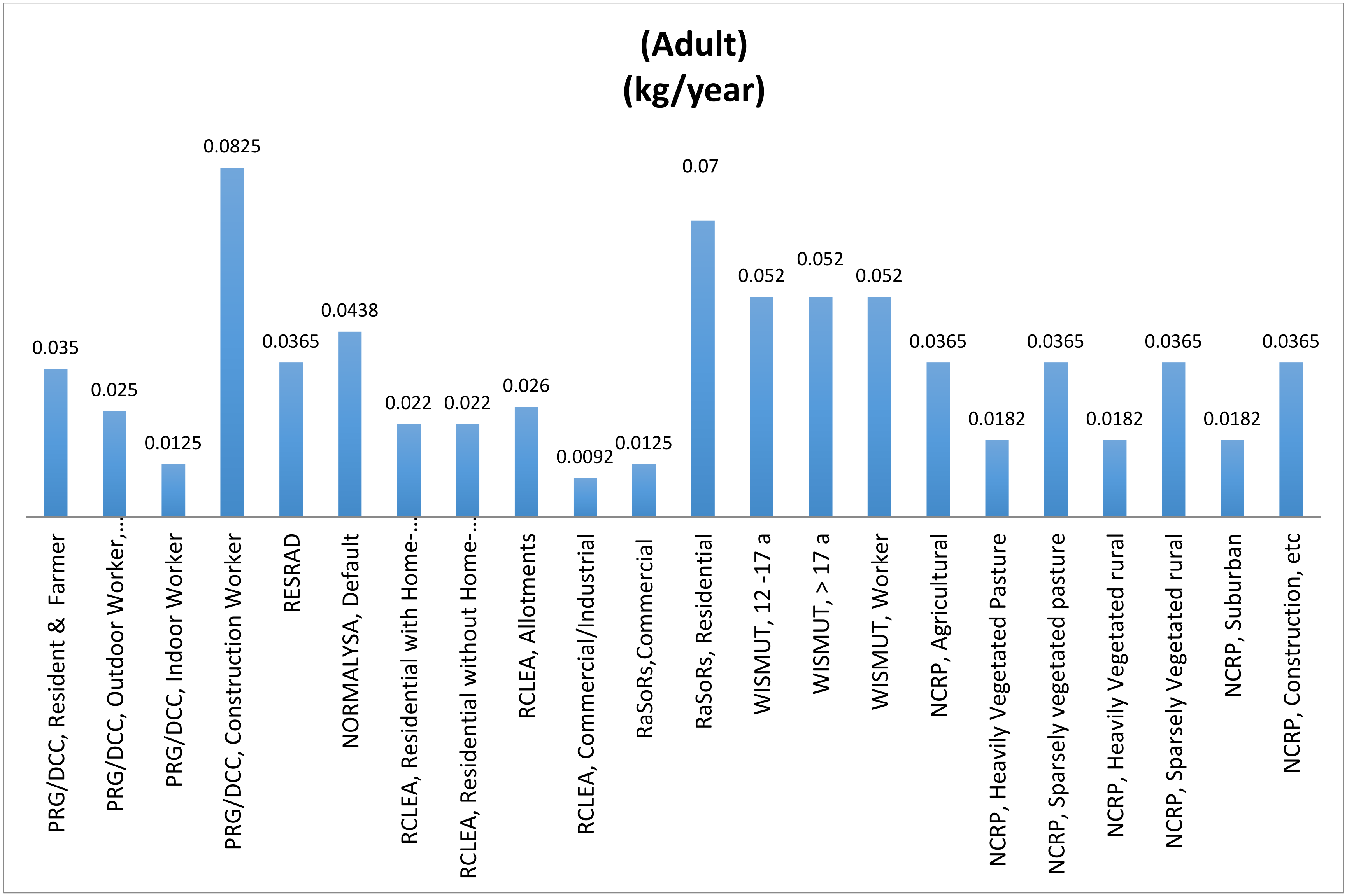


Figure 15: Soil consumption rates for adult (kg/yr).

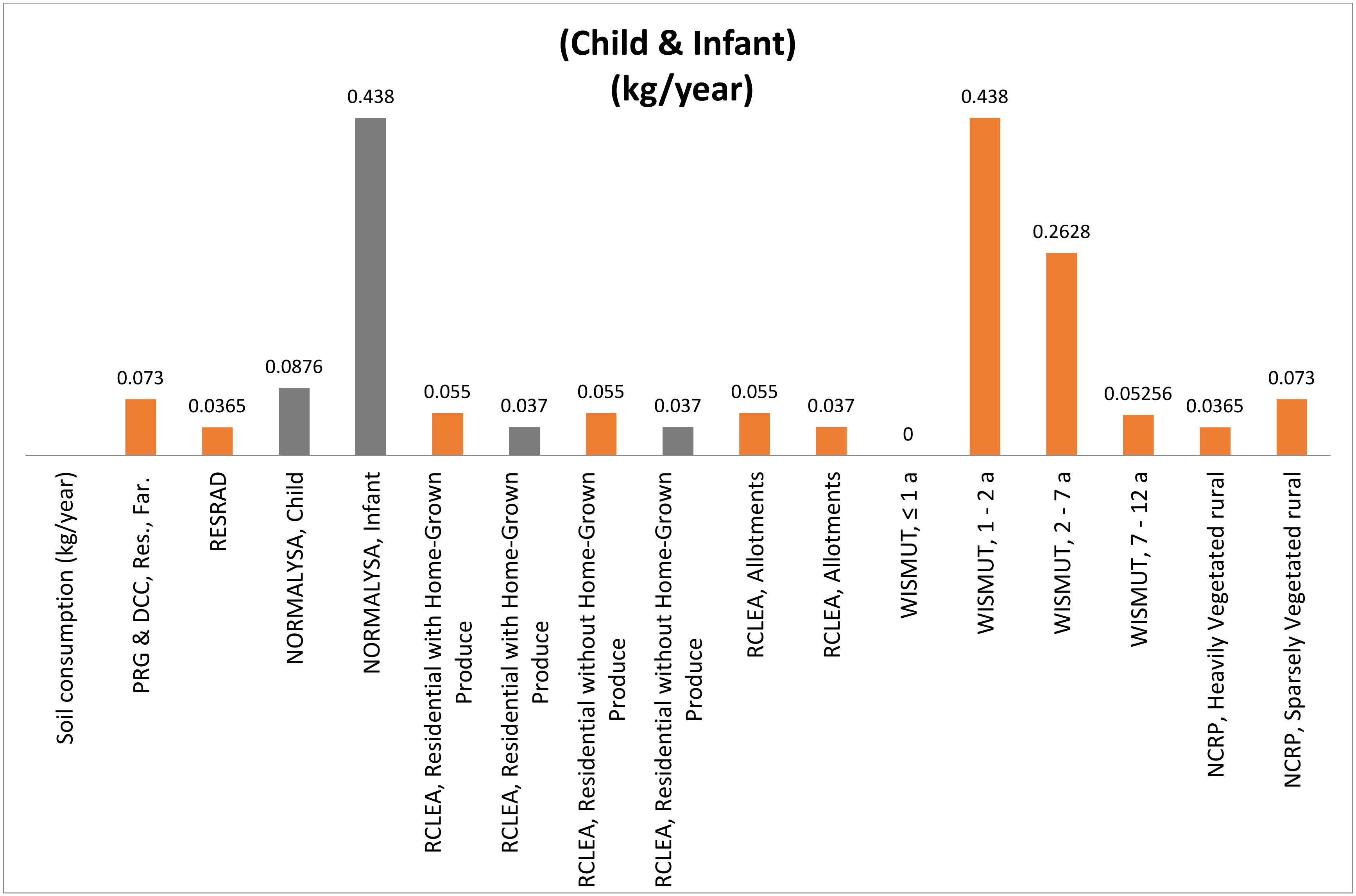


Figure 16: Soil consumption rates for child (orange) and infant (gray) (kg/yr).

Table 10: Soil consumption rates (kg/yr).

		Adult	Child
PRG, DCC and RSL ¥	Resident and Farmer	0.035	0.07
	Outdoor Worker and Composite	0.025	
	Indoor Worker	0.0125	
	Outdoor Worker, Composite Worker	0.0825	
	Recreator intake is only per day	0.1 (g/d)	0.2 (g/d)
RESRAD-ONSITE	Adult	0.0365	
NORMALYSA	Default	0.0438	
	Child:	0.0876	
	Infant	0.0438	
RCLEA* CLEA	Land Use		
	Residential with Home-Grown Produce, Infant	0.055	
	Residential with Home-Grown Produce, Child	0.037	
	Residential with Home-Grown Produce, Adult	0.022	
	Residential without Home-Grown Produce, Infant	0.055	
	Residential without Home-Grown Produce, Child	0.037	
	Residential without Home-Grown Produce, Adult	0.022	
	Allotments, Infant	0.055	
	Allotments, Child	0.037	
	Allotments, Adult	0.026	
	Commercial/Industrial, Adult	0.0092	
RaSoRS	Residential:	0.07	
	Commercial	0.0125	
WISMUT	Reference person		
	≤ 1 yr	0	
	1 - 2 yr	0.438	
	2 - 7 yr	0.2628	
	7 - 12 yr	0.05256	
	12 - 17 yr	0.05256	
	> 17 yr	0.05256	
	Worker	0.05256	
NCRP	Land-Use Scenario	Adult	Child
	Agricultural	0.0365	-
	Heavily Vegetated Pasture	0.01825	-
	Sparsely vegetated pasture	0.0365	-
	Heavily Vegetated rural	0.01825	0.0365
	Sparsely Vegetated rural	0.0365	0.073
	Suburban	0.01825	0.0365
	Construction, etc.	0.0365	-

¥ Resident and farmer scenarios use 350 day years. Construction worker, indoor worker and outdoor worker scenarios use 250 day years. Recreator scenario is site-specific with no assumed default occupancy factors.
* Note that these values take into account the rate and exposure frequency reported in Table 6.1 of CLR 10. [11]

3.6 Shielding Factors

Shielding factor refers to the reduction in the external exposure rate from on-site buildings or other structures while the individual is indoors. The meaning of shielding factor could be interpreted in two opposite ways. All the models in this study use a shielding factor as the reduction of the indoor external radiation compared to the outdoor, except RCLEA. For example, 0.8 indicates that the indoor external radiation is 20% lower than the outdoor levels. As shown in table 11, however, shielding factor in RCLEA indicates that the indoor external radiation is 80% lower than the outdoor levels. CROM does not consider shielding factors for the purpose of simple generic assessment. The default value is set at zero; however, there are options to input gamma and beta shielding factors.

Table 10: Shielding Factors.

PRG/DCC	Outdoor	1
	Indoor	0.4
RESRAD-ONSITE	Indoor	0.7
NORMALYSA	Outdoor	1
RCLEA	Indoors: Timber	0
	Concrete/Brick	0.9
RaSoRS	Basement or Slab	0.2
	Walls	0.8
	Outside	1
WISMUT	Outdoors	1
	Indoors, Solid Construction Buildings (Brick, Concrete)	0.1
	Indoors, Lightweight Construction Buildings (Wooden)	0.3
NCRP	Radionuclide-dependent, Appendix C	

3.7 Mass Loading Factors

A Mass Loading Factor parameter is the amount of soil deposited on the surface of plants before consumption. PRG/DCC calculators use Mass Loading Factors (MLF) in units of g soil / g fresh plant. PRG/DCC calculators provide plant-specific soil mass loading factors for 24 different kinds of crops. The MLF in PRG/DCC calculators are obtained from different sources: (1) Hinton, (2) EA and (3) Pinder and McLeod [15]. Source (2) is the *Updated Technical Background to the CLEA Model* that is used by RCLEA. PRG/DCC calculators and RCLEA share the same MLF source. [16]; however, RCLEA uses mass loading factors for only six kinds of crops in units of kg soil (dry weight) / kg crops (fresh weight). Table 12 lists MLFs for both models.

Table 11: Mass Loading Factors.

PRG & DCC	**Mass Loading Factors (g of soil/ g of fresh plant)**				
Apples	1.60E-04	Broccoli	1.01E-03	Onions	9.70E-05
Citrus	1.57E-04	Cabbage	1.05E-04	Peas	1.78E-04
Berries other than Strawberries	1.66E-04	Carrots	9.70E-05	Pumpkins	5.80E-05
Peaches	1.50E-04	Corn	1.45E-04	Snap Beans	5.00E-03
Pears	1.60E-04	Cucumbers	4.00E-05	Tomatoes	1.59E-03
Strawberries	8.00E-05	Lettuce	1.35E-02	White Potatoes	2.10E-04
Asparagus	7.90E-05	Lima Beans	3.83E-03	Cereal Grains	2.50E-01
Beets	1.38E-04	Okra	8.00E-05	Rice	2.50E-01
				Pasture	2.50E-01

RCLEA/CLEA*: Origin of Food and Amount of Soil on Vegetables

Crop	Soil Contamination of Home-Grown Vegetables (kg (dw)/kg(fw))
Brussels Sprouts	0.001
Cabbage	0.001
Carrot	0.0001
Leafy Salads	0.001
Onion (shallots and leeks)	0.001
Potato	0.0002

*Note that the values are adopted from Table 6.2 of CLR 10, where the value for leeks is cautiously adopted for onions and shallots. [12]

RESRAD-ONSITE uses a mass loading factor for inhalation and a mass loading factor for foliar deposition, both with a value of 1.0E-04 g/m^3. The use and definition of MLF in RESRAD-ONSITE are different from PRG/DCC calculators and RCLEA. RESRAD-ONSITE defines the MLF as the concentration of soil particles in the air and uses MLF to estimate the airborne dust concentration near the source (Dust Concentration). PRG/DCC calculators use different parameters for this purpose, such as soil resuspension multiplier (g dry soil per g fresh plant, it is equivalent to MLF for pasture and produce) and Particulate Emission Factor (PEF). There are a few types of PEFs in PRG/DCC calculators. They represent an estimate of the relationship between soil contaminant concentrations and the concentration of these contaminants in air as a consequence of particle resuspension from wind erosion or construction activities. The unit of PEF (m^3/kg) is the inverse of RESRAD-ONSITE MLF (g/m^3). RaSoRS uses an Outdoor Mass Loading Factor, which is defined as the concentration of resuspended soil. The model has two values for residential and commercial scenarios, at values 100 and 200 µg/m^3, respectively. RESRAD-ONSITE and RaSoRS use the name “mass loading” to express the resuspension. RaSoRS uses RESRAD as the reference for MLF used in the model. NORMALYSA, CROM, WISMUT and NCRP have different approach for mass loading factors, which may be included in transfer factors and mass interception factors.

IV. CONCLUSION

Radiation risk assessment models are important tools for decision makers. They 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 are constructed in different ways, as shown in Figure 17. This document shows an overview for some of the models that are used in the United States and internationally. It also shed some light on the default input parameters used by the models. This document is not intended to be a comparison between the models but rather a brief overview for the models and the default input parameters. It does not endorse any of the models or justify using certain default input parameters. The default input parameters are mainly used for the initial assessment. Different values of the default input parameters would produce different results for the assessment of a contaminated site. It is important to note that the regulatory frame of the agency that developed the models can affect the value of the parameters. To use a model, the regulatory frame under which the model was developed and parameter names and meanings should be taken into consideration. Models and their parameters cannot be used out of the context of the modeling approach and the regulatory frame.

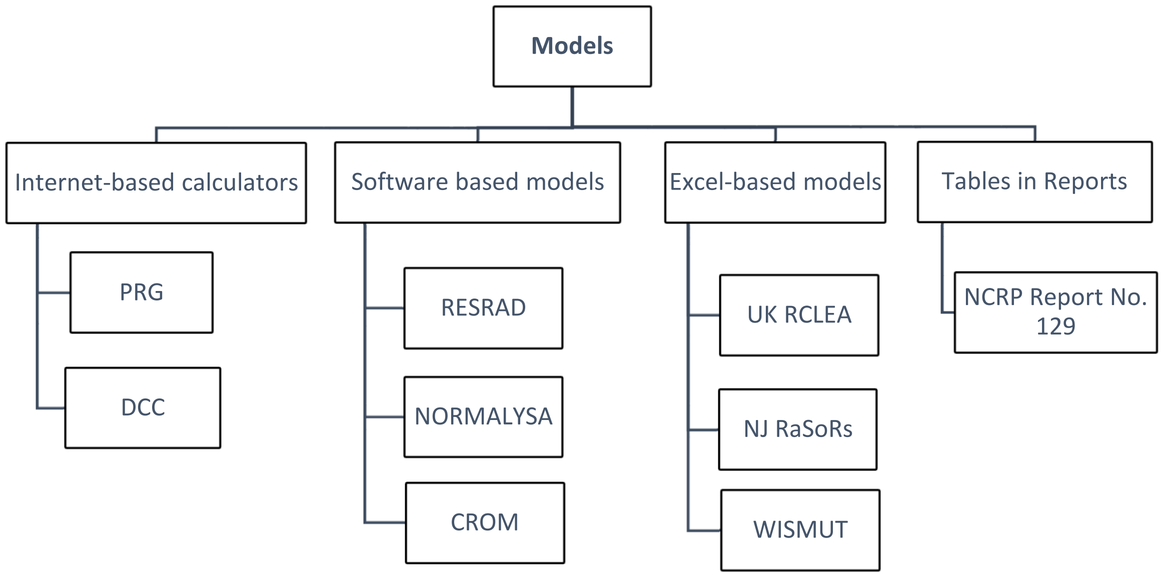


Figure 17: Models categories.

This study was limited both by the researcher's ability to become familiar with all of the models that were studied and the sponsoring organization's desire for the researcher to complete a companion study on models for contaminated buildings within the researchers' timeframe. There are several future projects on these same models that may be useful; however, these suggested follow-up projects would require a study researcher(s) with intimate knowledge of each model. This would most efficiently be done by the inclusion of each of the model developers or a designated model user expert. Such a study may be more readily achievable by an international organization, such as the IAEA. The IAEA MODARIA II Working Group 3 on Assessments and Control of Exposures to the Public and Biota for Planned Releases to the Environment is currently conducting such a study for modeling releases. This study has members from multiple countries/agencies conducting coordinated modeling runs to help better compare their models. This study was also originally conceived after the sponsor read a similar report on chemical risk assessment models issued by the European Commission in 2007, entitled "Derivation Methods of Soil Screening Values in Europe. A Review and Evaluation of National Procedures Towards Harmonisation". For such a future report for radiation models suitable for site remediation, there are three recommendations.

First, run each of the models using default parameters and several common scenarios for radionuclides that are common risk/cost drivers for the remediation of legacy sites. The scenarios that would most likely be suitable are subsistence farmer, suburban/urban residential, and outside commercial/industrial workers. A list of radionuclides that are common legacy contaminants can be found by looking at the lists used by the EPA Superfund program as "Common Superfund Contaminants" and those selected by NRC for their lookup tables, which are collectively: Ac-227, Am-241, C-14, Ca-45, Cl-36, Cm-242, Cm-243, Co-57, Co-60, Cs-134, Cs-137, Eu-152, Eu-154, Fe-55, H-3, I-129, I-131, Ir-192, Mn-54, Nb-94, Ni-59, Ni-63, Pb-210, Pu-238, Pu-239, Pu-240, Ra-226, Ra-228, S-35, Sc-46, Sr-90, Tc-99, Th-228, Th-230, Th-232, U-234, U-235, and U-238.

Second, run each model with the same scenarios and radionuclides but modified to use as consistent parameters as possible. Note that the models cannot match up all of their parameters, since the choices of parameters differ within each model.

Third, include other parameters, which may have been too difficult or time-consuming to ascertain for inclusion in this study. For example, the transfer factors used to estimate root uptake into plants from the soil or from the consumption of plants and water by farm animals may vary by different plant/animal types and elements within the models. In the PRG and DCC calculators, the following hierarchy of source documents for transfer factors was used:

1. Milk transfer factor (TF_{dairy} (day/L). IAEA, EA, NCRP, RESRAD. TF_{dairy} is the volumetric activity density in milk (pCi/L) divided by the daily intake of radionuclide (pCi/day).
2. Beef transfer factor (TF_{beef} (day/kg). IAEA, EA, NCRP, RESRAD. TF_{beef} is the mass activity density in beef (pCi/kg fresh weight) divided by the daily intake of radionuclide (in pCi/d).
3. Fish bioconcentration factor (BCF (L/kg). IAEA, RESRAD. BCF is the ratio of the radionuclide concentration in the fish tissue (pCi/kg fresh weight) from all exposure pathways relative to that in water (pCi/L).
4. Poultry transfer factor ($TF_{poultry}$ (day/kg). IAEA. $TF_{poultry}$ is the mass activity density in poultry (pCi/kg fresh weight) divided by the daily intake of radionuclide (in pCi/d).
5. Egg transfer factor (TF_{egg} (day/kg). IAEA. TF_{egg} is the mass activity density in egg (pCi/kg fresh weight) divided by the daily intake of radionuclide (in pCi/d).
6. Swine transfer factor (TF_{swine} (day/kg). IAEA. TF_{swine} is the mass activity density in swine (pCi/kg fresh weight) divided by the daily intake of radionuclide (in pCi/d).
7. Sheep Milk transfer factor ($TF_{sheep\text{-}milk}$ (day/L). IAEA. $TF_{sheep\text{-}milk}$ is the volumetric activity density in sheep milk (pCi/L) divided by the daily intake of radionuclide (pCi/day).
8. Sheep transfer factor (TF_{sheep} (day/kg). IAEA, EA. TF_{sheep} is the mass activity density in sheep (pCi/kg fresh weight) divided by the daily intake of radionuclide (in pCi/d).
9. Goat Milk transfer factor ($TF_{goat\text{-}milk}$ (day/L). IAEA. $TF_{goat\text{-}milk}$ is the volumetric activity density in goat milk (pCi/L) divided by the daily intake of radionuclide (pCi/day).

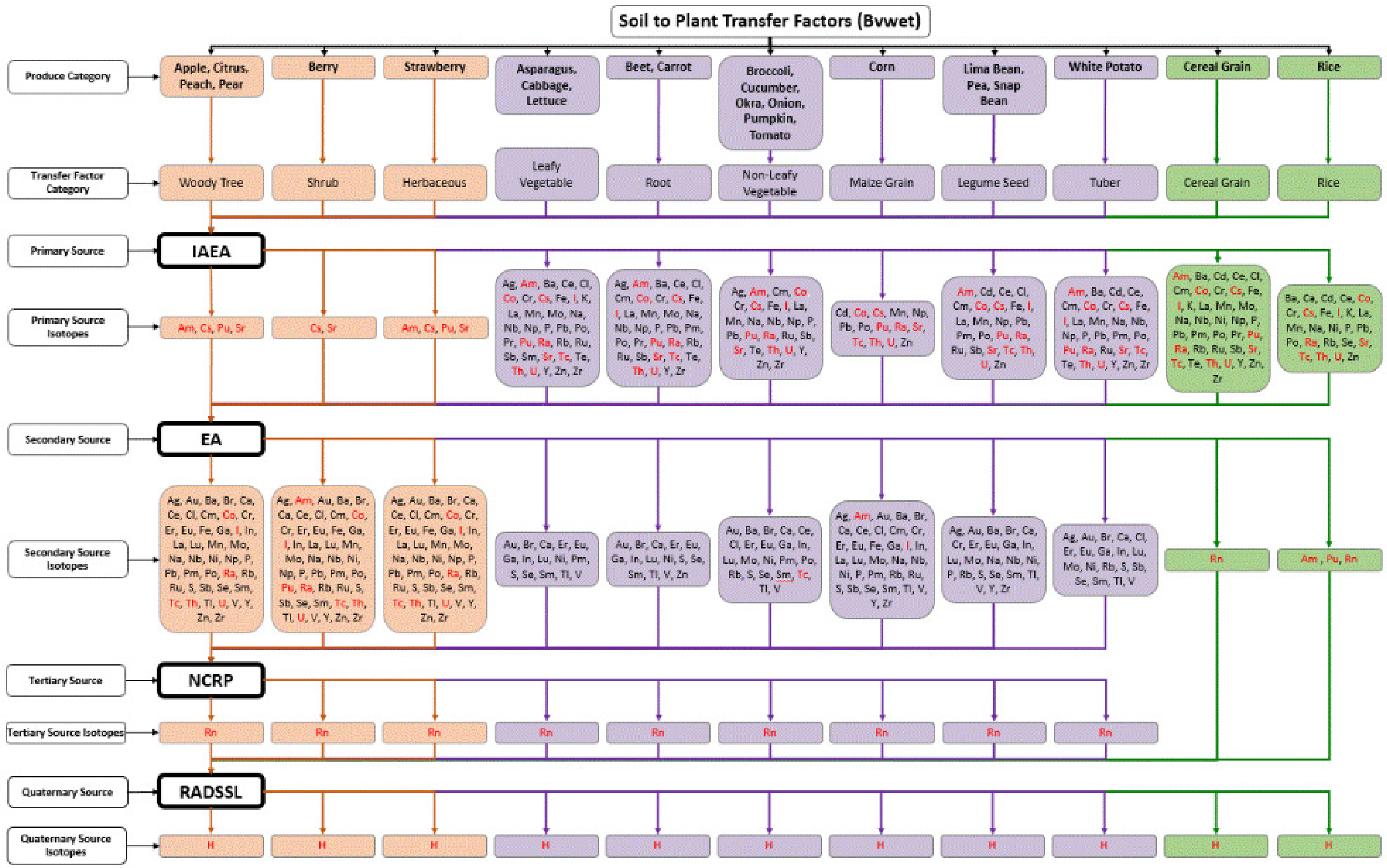
10. Goat transfer factor (TF_{goat} (day/kg). IAEA. TF_{goat} is the mass activity density in goat (pCi/kg fresh weight) divided by the daily intake of radionuclide (in pCi/d).

11. Soil to water partition coefficient (K_d (mg/kg-soil per mg/L water or simplified = L/kg). EPAKD, IAEA, SSL, RESRAD, BAES. (K_d is the ratio of the mass activity density (pCi/kg) of the specified solid phase (usually on a dry mass basis) to the volumetric activity density (Bq/L) of the specified liquid phase.

12. Soil to plant transfer factor-wet (Bv_{wet} (pCi/g plant per pCi/g soil). IAEA, EA, NCRP, SSL, RESRAD, BAES. The values for cereal grain are used from IAEA. (Bv_{wet} is the ratio of the activity concentration of radionuclide in the plant (pCi/kg wet mass) to that in the soil (pCi/kg dry mass). Note: Some Bv_{wet} values were derived from Bv_{dry} sources, assuming the ratio of dry mass to fresh mass was presented in the source documents. (For carbon, the only value in the hierarchy is found in RESRAD. This value is excluded as it over estimates root uptake. See section 2.5.4 for a detailed discussion of the carbon transfer factor derivation).

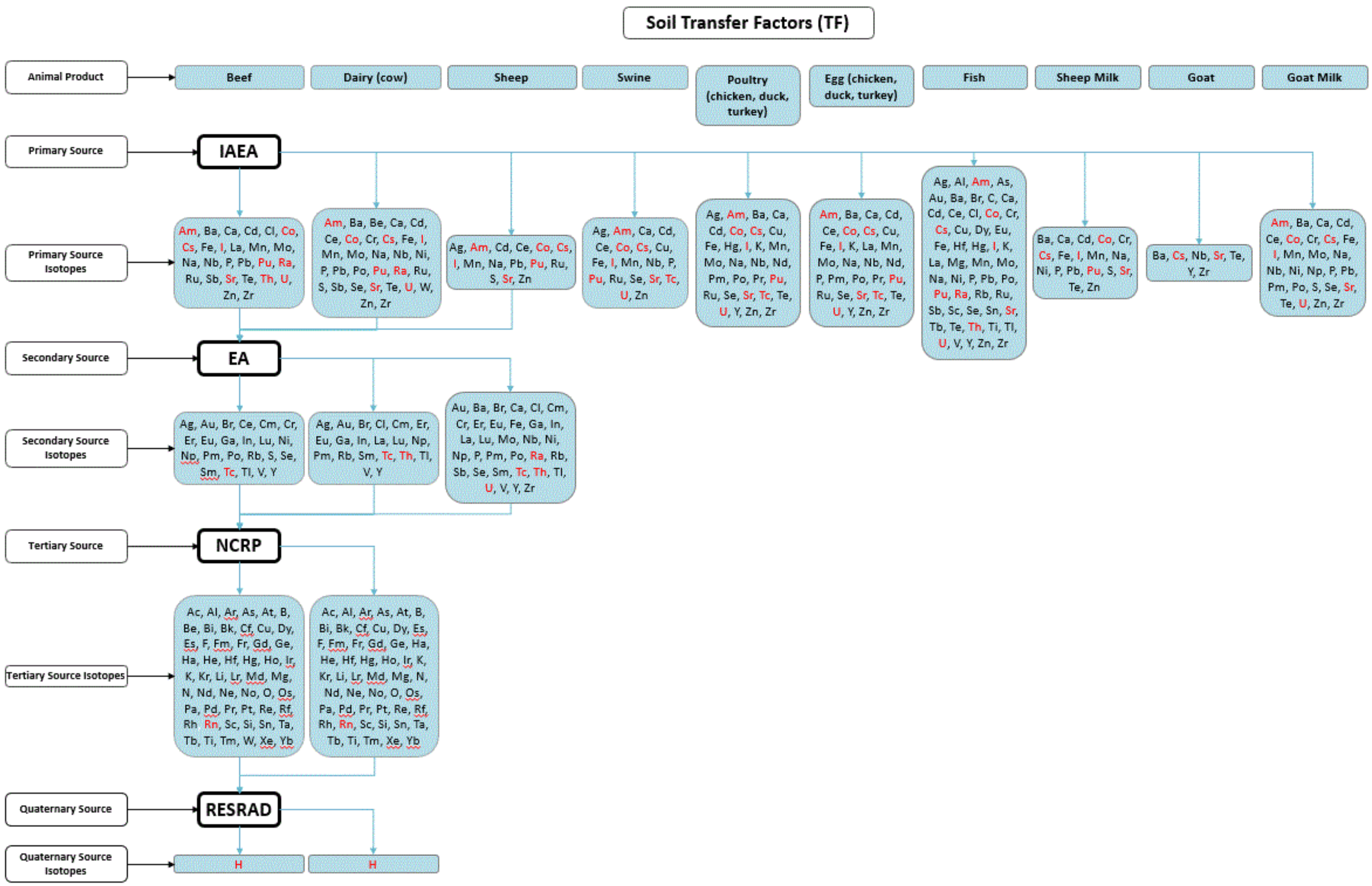
13. Soil to plant transfer factor-dry (Bv_{dry} (pCi/g plant per pCi/g soil). IAEA, EA, NCRP, SSL, RESRAD, BAES. The values for cereal grain are used. (Bv_{dry} is the ratio of the activity concentration of radionuclide in the plant (pCi/kg dry mass) to that in the soil (pCi/kg dry mass). Note: Some Bv_{dry} values were derived from Bv_{wet} sources, assuming the ratio of dry mass to fresh mass was presented in the source documents. (For carbon, the only value in the hierarchy is found in RESRAD. This value is excluded as it over estimates root uptake. See section 2.5.4 for a detailed discussion of the carbon transfer factor derivation).

This hierarchy of source documents, when summarized by produce and animal type, is shown in these illustrations:



- The red text elements are on the from the 'Common Isotopes' list on the calculator page.

Figure 18: PRG/DCC Soil to Plant Transfer Factor.



- The red text elements are on the from the 'Common Isotopes' list on the calculator page.
- The transfer factor source for Carbon does not fit in this hierarchy. Please refer to user guide section 2.5.4 for more information.

Figure 19: PRG/DCC Soil Transfer Factors.

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APPENDIX A: PRG/DCC

	Drinking Water Intake	
Farmer/ Resident, Adult	2.5 L/day	Tap water ingestion
Farmer/ Resident, Child	0.78 L/day	Tap water ingestion
Recreator, Adult	0.071 L/hr	Surface water
Recreator, Child	0.12 L/hr	Surface water

Fruit, Vegetables and Grains Consumption Rates (g/day)

Crop	Resident Adult		Resident Child		Farmer Adult		Farmer Child	
	FW	CW	FW	CW	FW	CW	FW	CW
Apple	73.7	38.2	72.2	37.4	84.7	43.9	82.9	43
Citrus	309.4	160.4	194.1	100.6	309.4	160.4	194.4	100.6
Berry	35.4	18.3	23.9	12.4	35.4	18.3	23.9	12.4
Peach	115.7	60	111.4	57.7	103.1	53.5	99.3	51.5
Pear	51.9	26.9	66.7	34.6	59.9	31.1	76.9	39.9
Strawberry	40.5	21	25.3	13.1	40.5	21	25.3	13.1
Asparagus	39.3	26.8	12	8.2	39.3	26.8	12	8.2
Beet	33.9	23.2	3.9	2.7	33.9	23.2	3.9	2.7
Broccoli	32	21.9	13.1	8.9	35.3	24.1	14.4	9.9
Cabbage	92.1	62.9	12.3	8.4	85.7	58.6	11.5	7.8
Carrot	27.3	18.7	14.9	10.2	24.4	16.6	13.3	9.1
Corn	59.8	40.9	23.8	16.3	82	56	32.7	22.3
Cucumber	82.4	56.3	25.4	17.3	54.9	37.5	16.9	11.5
Lettuce	37.5	25.6	4.2	2.9	37.5	25.6	4.2	2.9
Lima Bean	33.8	23.1	6.5	4.5	33.8	23.1	6.5	4.5
Okra	30.2	20.7	5.3	3.6	30.2	20.7	5.3	3.6
Onion	21.8	14.9	5.8	4	27.2	18.6	7.2	4.9
Pea	35.4	24.2	32.1	21.9	31.7	21.7	28.7	19.6
Pumpkin	64.8	44.2	45.2	30.9	64.8	44.2	45.2	30.9
Snap Bean	53.9	36.8	27.3	18.7	54.2	37	27.5	18.8
Tomato	80.3	54.8	29.7	20.3	94.2	64.4	34.9	23.8
White Potato	127.8	87.3	51.7	35.3	141.8	96.9	57.3	39.1
Rice	-	73.2	-	28.8		88.5	-	34.8
Cereal Grain	-	76.0	-	38.0	-	91.9	-	46.0

Meat and Poultry Consumption Rates (g/day)						
	Farmer Child (FW)	**Farmer Adult (FW)**	**Resident Child (FW)**	**Resident Adult (FW)**	**Farmer Child (CW)**	**Farmer Adult (CW)**
Dairy	994.7	676.4	n/a	n/a	n/a	n/a
Beef	62.8	165.3	n/a	n/a	31.1	81.7
Swine	33.7	92.5	n/a	n/a	16.6	45.7
Poultry	46.9	107.4	n/a	n/a	23.2	53.1
Egg	31.7	59.6	n/a	n/a	n/a	n/a

Fish Consumption Rates (g/day)			
Farmer Child (FW)	Farmer Adult (FW)	Farmer Child (CW)	Farmer Adult (CW)
57.4	831.8	35.2	509.9

Animal Consumption Rates (g/day)			
Animal	**Fodder**	**Soil**	**Water (L/day)**
Beef	11.77	0.5	53
Dairy	20.3	0.4	92
Goat	1.27	0.23	3.81
Goat Milk	1.59	0.29	8.75
Chicken	0.2	0.022	0.4
Duck	0.24	0.024	0.48
Turkey	0.68	0.068	1.36
Goose	0.33	0.033	0.66
Sheep	1.75	0.32	5.25
Sheep Milk	3.15	0.57	10.4
Swine	4.7	0.37	11.4

Soil Consumption (mg/day)	
Resident, Recreator, Farmer, Outdoor Worker, Composite, Adult	100
Resident, Recreator, Farmer, Child	200
Indoor Worker	50
Construction Worker	330

Breathing Rates (m^3/day)	
Resident, Recreator, Farmer, Child	10
Resident, Recreator, Farmer, Adult	20
Construction & Composite Worker	60

Mass Loading Factors (g of soil/ g of fresh plant)					
Apples	1.60E-04	Broccoli	1.01E-03	Onions	9.70E-05
Citrus	1.57E-04	Cabbage	1.05E-04	Peas	1.78E-04
Berries other than Strawberries	1.66E-04	Carrots	9.70E-05	Pumpkins	5.80E-05
Peaches	1.50E-04	Corn	1.45E-04	Snap Beans	5.00E-03
Pears	1.60E-04	Cucumbers	4.00E-05	Tomatoes	1.59E-03
Strawberries	8.00E-05	Lettuce	1.35E-02	White Potatoes	2.10E-04
Asparagus	7.90E-05	Lima Beans	3.83E-03	Cereal Grains	2.50E-01
Beets	1.38E-04	Okra	8.00E-05	Rice	2.50E-01
				Pasture	2.50E-01

Occupancy Factors

PRG & DCC	Resident	Farmer	Construction Worker	Indoor Worker	Outdoor Worker	Composite Worker	Recreator
Exposure Frequency (days/yr)	350	350	250	250	225	250	Site-specific
Exposure Duration (years)	General: 26 Adult: 20 Child: 6	General: 40 Adult: 34 Child: 6	1 yr	25	25	25	Site-specific
Exposure Time - indoor (hours/day)	16.4	10	-	-	-	-	Site-specific
Exposure Time - outdoor (hours/day)	1.75	12.16	-	-	-	-	Site-specific
Exposure Time (hours/day)	24	24	8	8	8	8	Site-specific
Exposure Time - away (hours/day)		1.83	-	-	-	-	Site-specific

APPENDIX B: RESRAD

Consumption Rates	
Drinking Water Intake (L/yr)	510
Leafy Vegetable (kg/yr)	14
Fruit, Vegetable and Grains (kg/yr)	160
Milk/ Dairy (L/yr)	92
Meat and Poultry (kg/yr)	63
Fish (kg/yr)	5.4
Crustacea and Mollusks (kg/yr)	0.9

Breathing Rates (m³/hr)

Resident Farmer	Suburban Resident	Industrial Worker	Recreationist
0.95	0.95	1.3	1.6

Soil Consumption (kg/yr)

0.0365

Animal Consumption Rates (kg/day)

	Fodder	Soil	Water (L/day)
Livestock (Beef) for meat	68	0.5	50
Livestock (Beef) for milk	55	0.5	160

Occupancy Factors

Fraction of time spent indoor	6.55E-01
Fraction of time spent outdoor	2.5E-01

Mass Loading Factor (g/m^3)

0.0001

Shielding Factors

Indoor	0.7

APPENDIX C: NORMALYSA

Drinking Water Intake (m^3/yr)			
Adult, Lactating mother		0.375	
Child, Infant		0.076	
Fruits, Vegetables and Grains Consumption Rates (kg/yr)			
Crop	Adult	Child	Infant
Cereals	52.048125	53.69175	64.9231875
Leafy vegetables	21.306915	6.44301	5.982795
Legume	2.1915	0.7305	0.7305
Roots	39.775725	40.10445	28.599075
Berries	6.64	3.33	3.33
Mushrooms	0.45	0.15	0.15
Garden food			
Fruits	3.52416	1.77096	3.23196
Garden berries	0.783	0.783	0.783
Leafy vegetables	21.306915	6.44301	5.982795
Legumes	2.1915	0.7305	0.7305
Roots	39.775725	40.10445	28.599075
Milk Consumption Rates (L/yr)			
Adult	31.32	Cow	
Child	53.69	Cow	
Infant	55.264	Cow	
Meat Consumption Rates (kg/yr)			
	Adult	Child	Infant
Beef	7.9	10.8	7.5
Sheep	0.208	0.208	0.198
Moose	0.74302968	1.01797604	0.70978558
Roe Dear	0.11483186	0.15732357	0.10969414
Wild boar	0.16211557	0.22210386	0.15486231
Fish &Seafood Consumption Rates (kg/yr)			
Marine/ Freshwater	Adult	Child	Infant
Cray fish	0.26240987	0.12111225	0.11438379
Fish	1.19055463	0.54948675	0.51895971
Mussels	0	0	0
Breathing Rates (m^3/h)			
Infant/ Child		0.92	
Adult		0.64	

Soil Consumption Rates (kg/hr)			
Adult	5.0E-6		
Child	1.0E-5		
Infant	5.0E-5		
Animal Consumption Rates (kg_{DW}/day)			
Ingestion of pasture by meat animals	11.4	Cow	
Ingestion rate of pasture by milk animals	9.1	Cow	
Ingestion rate of soil by meat animals	0.7	Cow	
Ingestion rate of soil by milk animals	0.6	Cow	
Ingestion rate of water by meat animals (m^3/d)	0.06	Cow	
Ingestion rate of water by milk animals (m^3/d)	0.04	Cow	
Occupancy Factors			
Fraction of time exposed outdoors		0.25	For all groups
Shielding Factors			
	1		

APPENDIX D: CROM

Drinking Water Intake (m3/yr)				
Adult		0.600		Water and Beverages
Infant		0.260		Water and Beverages
Fruits, Vegetables and Grains including potatoes (kg/yr)				
Adult	410			
Infant	150			
Milk Consumption Rates (L/yr)				
Adult	250			
Infant	300			
Meat Consumption Rates (kg/yr)				
Adult	100			
Infant	40			
Fish & Seafood Consumption Rates (kg/yr)				
	Adult	Infant		
Freshwater fish	30	15		
Marine fish	50	25		
Marine fish	15	0		
Inhalation Rates (m^3/yr)				
	0-1	1400		
	1--2	1898		
	2--7	3197		
	7--12	5577		
	12--17	7337		
	>17	8322		
Animal Consumption Rates (kg/yr)				
	Fodder kg dw/day	Water m^3/day		
Large Animal for milk	16	0.06		
Large Animal for meat	12	0.04		
Occupancy Factors				
	Adult		Infant	
External Exposure	(Hour/yr)	Fraction	(Hour/yr)	Fraction
Surface contaminated owing to air deposition	8760	1	8760	1
Working /playing over contaminated sediment	1600	0.18	1000	0.12
Submersion in air	8760	1	8760	1
Garden and ground exposure from irrigation	500	0.06	500	0.06

APPENDIX E: RCLEA

Fruits, Vegetables and Grains Consumption Rates (kg fw/ kg body weight /yr)			
	Adult	Child	Infant
Brussels Sprouts	0.2555	0.2482	0.4745
Cabbage	0.24455	0.22995	0.5475
Carrot	0.23725	0.365	0.657
Leafy Salads	0.17885	0.19345	0.4015
Onion (shallots and leeks)	0.1606	0.22995	0.3358
Potato	1.24	2.0805	2.7375

Breathing Rates (m^3/h)			
		Active	Passive
Male	Infant	0.339	0.124
Male	Child	1.103	0.404
Male	Adult	1.456	0.485
Female	Infant	0.32	0.117
Female	Child	1.1	0.403
Female	Adult	1.234	0.411

Soil Consumption Rates (kg dw/yr)	
Land Use	
Residential with Home-Grown Produce, Infant	0.055
Residential with Home-Grown Produce, Child	0.037
Residential with Home-Grown Produce, Adult	0.022
Residential without Home-Grown Produce, Infant	0.055
Residential without Home-Grown Produce, Child	0.037
Residential without Home-Grown Produce, Adult	0.022
Allotments, Infant	0.055
Allotments, Child	0.037
Allotments, Adult	0.026
Commercial/Industrial, Adult	0.0092

Shielding Factors	
Indoors: Timber	0
Indoors: Concrete/Brick	0.9

Origin of Food and Amount of Soil on Vegetables	
	Soil Contamination of Home-Grown Vegetables
Crop	(kg(dw)/kg(fw))
Brussels Sprouts	0.001
Cabbage	0.001
Carrot	0.0001
Leafy Salads	0.001
Onion (shallots and leeks)	0.001
Potato	0.0002

Occupancy Factors						
	Adult		Child		Infant	
Fraction of time spent:	Active	Passive	Active	Passive	Active	Passive
Residential with Home-Grown Produce, indoor	0.125	0.708	0.083	0.667	0.125	0.750
Residential with Home-Grown Produce, outdoor	37.96	0.063	0.083	0	0.083	0.042
Residential without Home-Grown Produce, indoor	0.125	0.708	0.083	0.667	0.125	0.750
Residential without Home-Grown Produce, outdoor	37.96	0.063	0.083	0	0.083	0.042
Allotments, indoor	0.125	0.708	0.083	0.667	0.125	0.750
Allotments, outdoor	34.675	0.047	0.012	0.012	13.14	0.018
Commercial/Industrial, indoor	0.052	0.144	-	-	-	-
Commercial/Industrial, outdoor	0.013	0.006	-	-	-	-

APPENDIX F: RaSoRS

Drinking Water Intake (L/yr)		
Adult	700	
Fruits, Vegetables and Grains Consumption Rates (g/yr)		
Residential	17136	
Commercial	0	
Soil Consumption Rates (g/yr)		
Residential	70	
Commercial	12.5	
Breathing Rates (m^3/hr)		
	Residential	Commercial
Indoor on site	0.63	1.4
Outdoor on site	1.4	1.4
Occupancy Factors		
	Residential	Commercial
Fraction time spent indoors on site (%)	68	18
Fraction time spent outdoors on site (%)	8	5
Mass Loading Factors		
	Residential	Commercial
Outdoor mass loading (µg/m^3)	100	200
Shielding Factors		
Basement or slab	0.2	
Walls	0.8	
Outside	1	

APPENDIX G: WISMUT

Consumption Rates							
Reference Person	≤ 1 yr	1 - 2 yr	2 - 7 yr	7 - 12 yr	12 -17 yr	> 17 yr	Worker
Drinking Water Intake (L/yr)	55	100	100	150	200	350	
Milk Including Milk products (L/yr)	45	160	160	170	170	130	
Meat Including meat products (kg/yr)	5	13	50	65	80	90	
Fish &Seafood consumption (kg/yr)	0.5	3	3	4.5	5	7.5	
Vegetable products	75	138	227	259	271	253	
Cereals, cereal products (kg/yr)	12	30	80	95	110	110	
Fresh fruit, fruit products, juice (kg/yr)	25	45	65	65	60	35	
Potatoes, root vegetables, juice (kg/yr)	30	40	45	55	55	55	
Leafy vegetables	3	6	7	9	11	13	
Vegetables, vegetable products, juice (kg/yr)	5	17	30	35	35	40	
Soil consumption (kg/yr)	0	5 E-5	3E-5	6E-6	6E-6	6E-6	6E-6
Breathing Rates (m^3/h)	0.12	0.22	0.36	0.64	0.84	0.93	1.2

Animal Consumption Rates (kg/day)			
	Fodder	Soil	Water (L/day)
Cattle	65	0.5	75

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

Occupancy Factors					
Exposure site	Ref. person	Exposure time (hours)			
1. Indoors:	Worker	Up to 2000			
	Member of the public	7000			
2. Outdoors:	Worker	Up to 2000			
	Member of the public	Up to 2000			
Where the following values result for a member of the public, depending on local conditions, from:					
2.1 uncultivated mine dumps or uncultivated areas, contaminated by mining residues	≤ 1 yr	1 - 2 yr	2 - 7 yr	7 - 12 yr	12 -17 yr
	0	100	250	250	250
2.2 garden areas	Member of the public	1000			
2.3 traffic areas	Member of the public	1000			
2.4 parks and recreation centers, children's play areas	Member of the public	1000			

APPENDIX H: NCRP

Fruit, Vegetable and Grains (kg/yr)	**300**		
Milk consumption (L/yr)	200		
Meat and poultry consumption (kg/yr)	100		
Inhalation Rates (m^3/day)			
Land-use	Outdoor	Indoor	
Agricultural	35	-	
Heavily Vegetated Pasture	35	-	
Sparsely vegetated pasture	35	-	
Heavily Vegetated rural	30	20	
Sparsely Vegetated rural	30	20	
Suburban	25	20	
Construction, etc.	35	-	
Soil Consumption Rates (g/day)			
Land-Use Scenario	Adult	Child	
Agricultural	0.1	-	
Heavily Vegetated Pasture	0.05	-	
Sparsely vegetated pasture	0.1	-	
Heavily Vegetated rural	0.05	0.1	
Sparsely Vegetated rural	0.1	0.2	
Suburban	0.05	0.1	
Construction, etc.	0.1	-	
Animal Consumption Rates (kg/day)			
	Fodder	Soil	Water
Milk cows	16	-	-
Beef cattle, game	8	-	-
Pigs	2.4	-	-
Calves	1.9	-	-
Lamb	1.1	-	-
Chicken	0.07	-	-
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			