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To contact the EPA for questions about radiation risk assessment and/or this calculator, please [CONTACT US](#).

The calculator may experience brief periods of disruption from 7a - 3p EST on Saturday, June 18th due to ORNL scheduled maintenance.

PRG User's Guide

[PDF of User's Guide.](#)

Welcome to the EPA's "Preliminary Remediation Goals for Radionuclide Contaminants at Superfund Sites" (PRG) user's guide. Here you will find descriptions, equations, and default exposure parameters used to calculate the risk-based PRGs. Additional guidance is also provided on sources of parameters and proper PRG use. It is suggested that users read the [PRG FAQ](#) page before proceeding. The user guide is extensive, so please use the "Open All Sections" and "Close All Sections" links below as needed. Individual sections can be opened and closed by clicking on the section titles. Before proceeding through the user's guide, please read the [Disclaimer](#).

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Disclaimer

This guidance document sets forth EPA's recommended approaches, based upon currently available information, with respect to risk assessment for response actions at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites (commonly known as Superfund). This document does not establish binding rules. Alternative approaches for risk assessment may be found to be more appropriate at specific sites (e.g., where site circumstances do not match the underlying assumptions, conditions, and models of the guidance). The decision whether to use an alternative approach and a description of any such approach should be documented. Accordingly, when comments are received at individual sites questioning the use of the approaches recommended in this guidance, the comments should be considered and an explanation provided for the selected approach.

The policies set out in the Radionuclide PRG User Guide provide guidance to EPA staff. It also provides guidance to the public and regulated community on how EPA intends the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) be implemented. EPA may change this guidance in the future, as appropriate.

It should also be noted that calculating a PRG addresses neither human radionuclide dose or noncancer toxicity nor potential ecological risk. Of the radionuclides generally found at CERCLA sites, only uranium has potentially significant noncancer toxicity. When assessing sites with uranium as a contaminant, it may also be necessary to consider the noncancer toxicity of uranium using other tools, such as EPA's Regional Screening Levels ([RSLs](#)) for Chemical Contaminants at Superfund Sites electronic calculator for uranium in soil, water, and air and the [WTC](#) for uranium inside buildings. EPA's [SPRG](#) Calculator should be used to assess radionuclide cancer risk for hard outside surfaces and the [BPRG](#) Calculator for radionuclide cancer risk inside buildings. EPA's [DCC](#) Calculator should be used to assess radionuclide dose for soil, water, and air, [BDCC](#) Calculator for radionuclide dose inside buildings, and the [SDCC](#) Calculator for radionuclide dose for hard outside surfaces. Similarly, some sites with radiological contaminants in sensitive ecological settings may also need to be evaluated for potential ecological risk. EPA's guidance ([Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessment](#)) contains an eight step process for using benchmarks for ecological effects in the remedy selection process.

This web calculator may be used to develop generic PRGs for radionuclides for several different exposure scenarios. The calculator is flexible and may be used to derive site-specific PRGs as more site characterization is obtained (EPA 2000a). Models reviewed by EPA in the [Soil Screening Guidance for Radionuclides: Technical Background Document](#) are presented in Section 3-2. This report provides a detailed technical analysis of five unsaturated zone fate and transport models for radionuclides. This report supports the information provided in [Part 3 - Unsaturated Zone Models for Radionuclide Fate and Transport](#) [PDF 383KB, 25 pages] of the [Soil Guidance for Radionuclides: Technical Background Document](#) on determining the general applicability of the models to surface conditions and assessing

PRGs for Radionuclides

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each model's potential applicability to the soil screening process.

1. Introduction

A purpose of this guidance is to provide a PRG calculation tool to assist risk assessors, remedial project managers, and others involved with risk assessment and decision-making at CERCLA sites in developing PRGs. This database is based on [Risk Assessment Guidance for Superfund: Volume I. Human Health Evaluation Manual \(Part B. Development of Risk-based Preliminary Remediation Goals\)](#) (RAGS Part B). RAGS Part B provides guidance on calculating risk-based PRGs. Initially used at the scoping phase of a project using readily available information, risk-based PRGs may be modified based on site-specific data gathered during the RI/FS study. PRG development and screening should assist staff in streamlining the consideration of remedial alternatives. Chemical-specific PRGs are from two general sources. These are: (1) concentrations based on potential Applicable or Relevant and Appropriate Requirements (ARARs) and (2) risk-based concentrations. ARARs include concentration limits set by other environmental regulations, such as Safe Drinking Water Act maximum contaminant levels (MCLs). The second source for PRGs, and the focus of this database tool, is risk-based calculations that set concentration limits using carcinogenic toxicity values under specific exposure conditions.

The recommended approach for developing remediation goals is to identify PRGs at scoping, modify them as needed at the end of the RI or during the FS based on site-specific information from the baseline risk assessment, and ultimately select remediation levels in the Record of Decision (ROD). In order to set radionuclide-specific PRGs in a site-specific context, however, assessors must answer fundamental questions about the site. Information on the radionuclides that are present onsite, the specific contaminated media, land-use assumptions, and the exposure assumptions behind pathways of individual exposure is necessary in order to develop radionuclide-specific PRGs. The PRG calculator provides the ability to modify the standard default PRG exposure parameters to calculate site-specific PRGs.

This database tool presents standardized risk-based PRGs and variable risk-based PRG calculation equations for radioactive contaminants. Ecological effects are not considered in the calculator for radionuclides PRGs.

PRGs are presented for resident soil, outdoor worker soil, indoor worker soil, composite worker soil, recreator soil, farmer soil, construction worker soil, tap water, air, farm products, and fish ingestion. The risk-based PRGs for radionuclides are based on the carcinogenicity of the contaminants. Cancer slope factors (SFs) used are provided by the [Center for Radiation Protection Knowledge](#). The main report is [Calculations of Slope Factors and Dose Coefficients](#), and the tables of slope factors are in a separate [appendix](#).

Non-carcinogenic effects are not considered for radionuclide analytes except for uranium, for which both carcinogenic and non-carcinogenic effects are considered. To determine PRGs for the chemical toxicity of uranium, and for other chemicals, go to the [Regional Screening Levels for Chemical Contaminants at Superfund Sites](#) webpage.

The standardized PRGs are based on default exposure parameters and incorporate exposure factors that present reasonable maximum exposure (RME) conditions. This database tool presents PRGs in both activity and mass units. Once this database tool is used to retrieve standard PRGs or calculate site-specific PRGs, it is important to clearly demonstrate the equations and exposure parameters used in the calculations. Discussion of the assumptions that go into the calculated PRGs should be included in the document where the PRGs are presented, such as a Remedial Investigation (RI) Report or Feasibility Study.

This website combines current [Center for Radiation Protection Knowledge](#) SFs with standard exposure factors to estimate contaminant concentrations in environmental media (biota, air, soil, and water) that are protective of humans (including sensitive groups) over a lifetime. Sufficient knowledge about a given site may warrant the use of site-specific assumptions that may differ from the defaults. Exceeding a PRG usually suggests that further evaluation of the potential risks is appropriate. The PRG concentrations presented on this website can be used to screen pollutants in environmental media, trigger further investigation, and provide initial cleanup goals, if applicable. PRGs should be applied in accordance with guidance from EPA Regions.

In addition to this guidance, for relevant training, see the internet-based course "[Radiation Risk Assessment: Updates and Tools](#)."

2. Understanding the PRG Website

2.1 General Considerations

PRGs are isotope concentrations that correspond to certain levels of risk from exposure to air, soil, water, and biota. Slope Factors (SFs), for a given radionuclide represent the risk equivalent per unit intake (i.e., ingestion or inhalation) or external exposure of that radionuclide. In risk assessments, these SFs are used in calculations with radionuclide concentrations and exposure assumptions to estimate risk from exposure to radioactive contamination. The calculations may be rearranged to generate PRGs for a specified level of

risk. SFs may be specified for specific body organs or tissues of interest or as a weighted sum of individual organ risk, termed the effective risk equivalent. These SFs may be multiplied by the total activity of each radionuclide inhaled or ingested per year, or the external exposure concentration to which a receptor may be exposed, to estimate the risk to the receptor. Slope Factors used are provided by the [Center for Radiation Protection Knowledge](#). The main report is [Calculations of Slope Factors and Dose Coefficients](#), and the tables of DCFs are in a separate [appendix](#).

Inhalation slope factors are tabulated separately for each of the three lung absorption types considered in the lung model currently recommended by the International Commission on Radiological Protection (ICRP) and, where appropriate, for inhalation of radionuclides in vapor or gaseous forms.

The designations "F", "M", and "S" presented in the Radionuclide Table under the heading "ICRP Lung Type" refer to the lung absorption type for inhaled particulate radionuclides, expressed as fast (F), medium (M), or slow (S), as used in the current ICRP model of the respiratory tract. The inhalation slope factor values tabulated in the Radionuclide Table for each radionuclide have been selected based on the following guidelines: (1) For those elements where Table 4.1 of Federal Guidance Report No. 13 (and Table 2 of ICRP Publication 72) specifies a recommended default lung absorption type for particulates, the inhalation slope factor for that type is tabulated in the Radionuclide Table for each radioisotope of that element; (2) For those elements where no specific lung absorption type is recommended and multiple types are indicated as plausible choices, the inhalation slope factor reported in the Radionuclide Table for each radioisotope of that element is the maximum of the values for each of the plausible lung absorption types; and (3) Where Federal Guidance Report No. 13 specifies risk coefficients for multiple chemical forms of certain elements (tritium, carbon, sulfur, iodine, and mercury), the inhalation slope factor value for the form estimated to pose the maximum risk is reported in the Radionuclide Table, in most cases.

Inhaled particulates are assumed to have an activity median aerodynamic diameter (AMAD) of 1 μm , as recommended by the ICRP for consideration of environmental exposures in the absence of specific information on physical characteristics of the aerosol. Where appropriate, radionuclides that may be present in gas or vapor form are designated by "G" and "V", respectively; such radionuclides include tritium, carbon, sulfur, nickel, ruthenium, iodine, tellurium, and mercury.

The most common land uses and exposure assumptions are included in the equations on this website: [Resident Soil](#), [Composite Worker Soil](#), [Outdoor Worker Soil](#), [Indoor Worker Soil](#), [Construction worker Soil](#), [Farmer Soil](#), [Recreator Soil](#), [resident Air](#), [Composite Worker Air](#), [Outdoor Worker Air](#), [Indoor Worker Air](#), [Construction worker Air](#), [Farmer Air](#), [Recreator Air](#), [Tapwater](#), [Soil to Groundwater](#), and [Ingestion of Fish](#).

The PRGs are generated with [standard exposure route equations](#) using EPA SFs and exposure [parameters](#). The PRG calculator receptor represents a high end (RME) exposed individual, as does the BPRG receptor (for a person exposed to contamination indoors). Since the PRG RME is often outside and the BPRG RME is always indoors, an individual receiving both indoor and outdoor exposures at a site should be protected. For the calculation of soil ingestion slope factors, area correction factors, and gamma shielding factors, a standard soil density of 1.6 g/cm^3 has been used.

2.2 PRG Output Options

The calculator offers four options for calculating PRGs. Previous versions of this calculator employed slope factors that included progeny ingrowth for 100 years, designated "+D." The +D slope factors are no longer included in the pick list; see section 2.9.2 to learn more. The PRGs presented in sections 2.2.1 and 2.2.2 independently model progeny during migration to groundwater and biota uptake, while the +D PRGs did not. This section describes the potential applications of the four choices and recommends a default PRG calculation.

2.2.1 PRG Output Option #1: Assumes period of peak risk (with decay and progeny ingrowth)(Peak PRG)

This is the preferred PRG calculation option and is marked as the default selection in the calculator. The Peak PRG is calculated for the time period when the parent and progeny activities present the most risk. The underlying assumption of the Peak PRG option is that a pure isotope was released and progeny begin ingrowth and decay. This PRG is protective, as future progeny may contribute more risk than the parent. When a single isotope is selected, the calculator identifies all the progeny in the chain. The PRGs for each progeny are combined with the parent based on their fractional contribution (FC). The FC is determined by branching fractions, where a progeny may decay into more than one isotope. Section 2.2.2 presents details on calculating the FC. Unlike previous PRG output options that included progeny contribution (i.e., +D PRGs as discussed in section 2.9.2.), the Peak PRG models each progeny independently of the parent for half-life, migration to groundwater, and biota uptake. The PRG provided in the output is the inverse sum of the reciprocal PRGs of the parent and all the progeny present at the period of peak risk. All PRG equation images are presented without a radioactive decay term; however, decay and ingrowth is included in this PRG

option.

When the Peak PRG output option is selected, the PRG Calculator shows the individual progeny contributions for the total PRG. At the top of the output page, the results are separated into tabs by media. In the Peak PRG output, the individual exposure routes are presented separately. This is done to help determine which exposure routes are risk drivers that may help to focus site-specific remedial efforts. The period of peak risk may differ for some exposure routes (e.g., external, soil ingestion, food ingestion, and inhalation) as well as the total Peak PRG. Forward risk calculations are also available for this output option.

The Peak PRG output option can be run for an infinite time period or a user-defined time period.

2.2.1.1 Infinite Time

The default setting for the Peak PRG option is to search for the period of peak risk out to infinity. To accomplish this, the Peak PRG uses a [Bateman](#) solver to determine the parent and progeny activities out to a trillion years. This isotopic activity curve is then converted to risk, and another routine selects the time period with the most risk from parent and progeny and determines the parent activity (PRG) that would represent the target risk. Users should note that for long-lived isotopes that have a peak risk that begins in the future, progeny are likely already ingrown, and the secular equilibrium (SE) PRGs may be appropriate. This [ORNL Technical Memorandum](#) offers explanation of the derivation of the Peak PRGs.

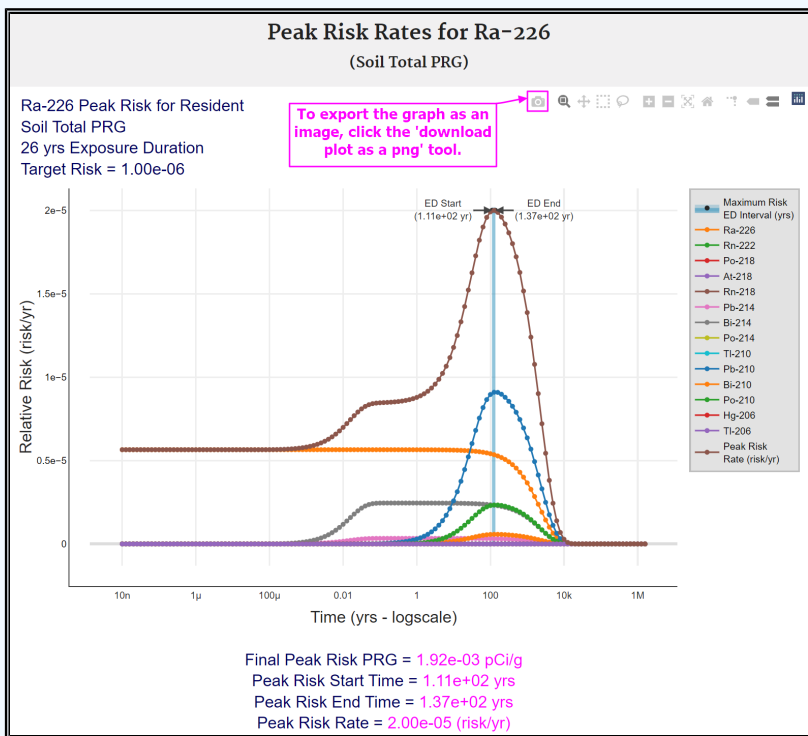
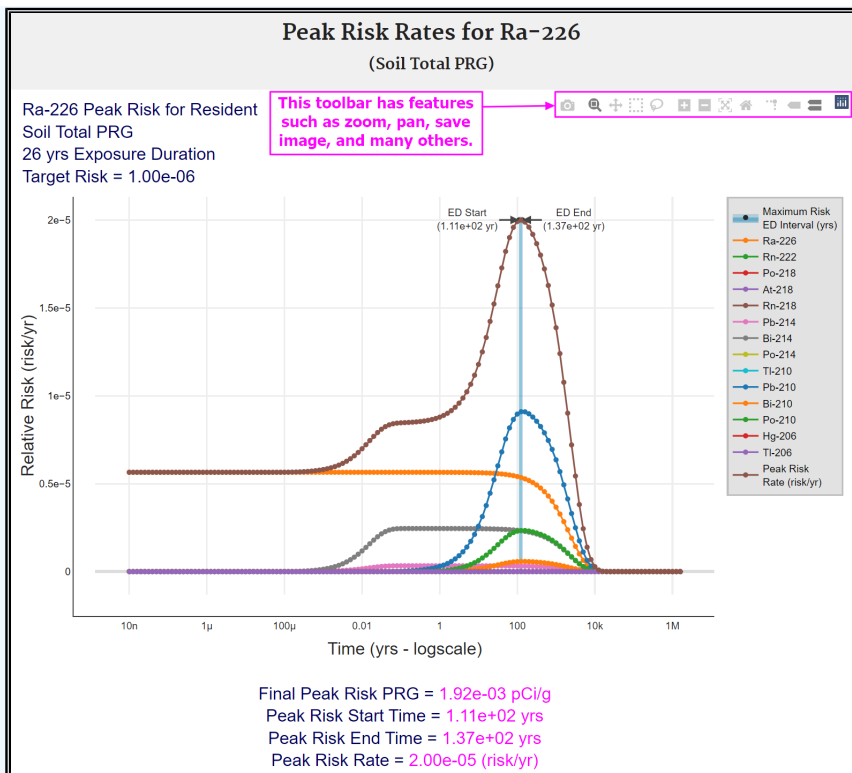
2.2.1.2 User-defined Time Period

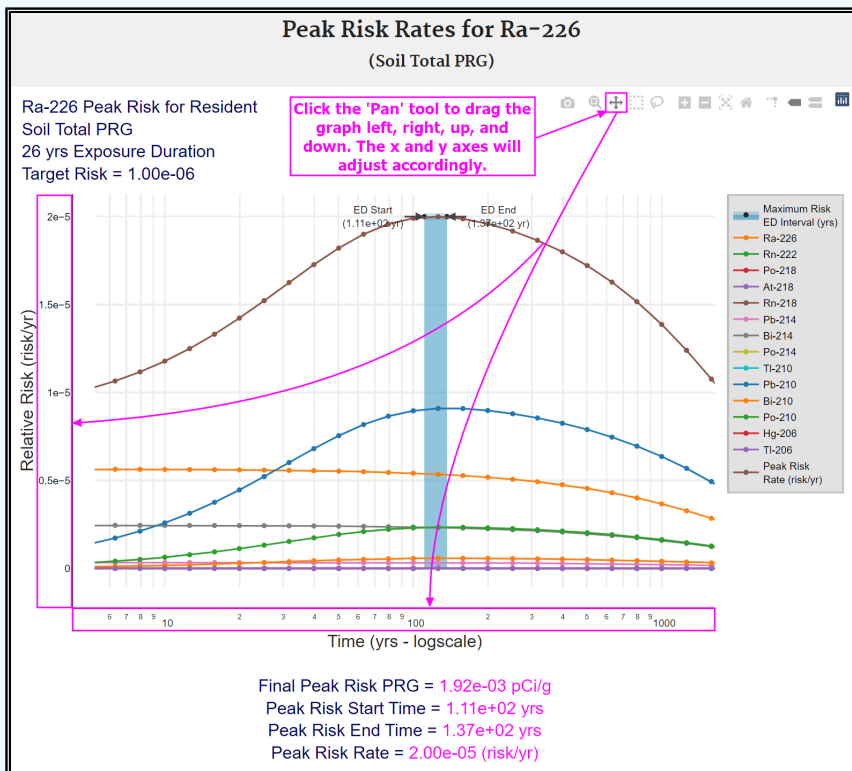
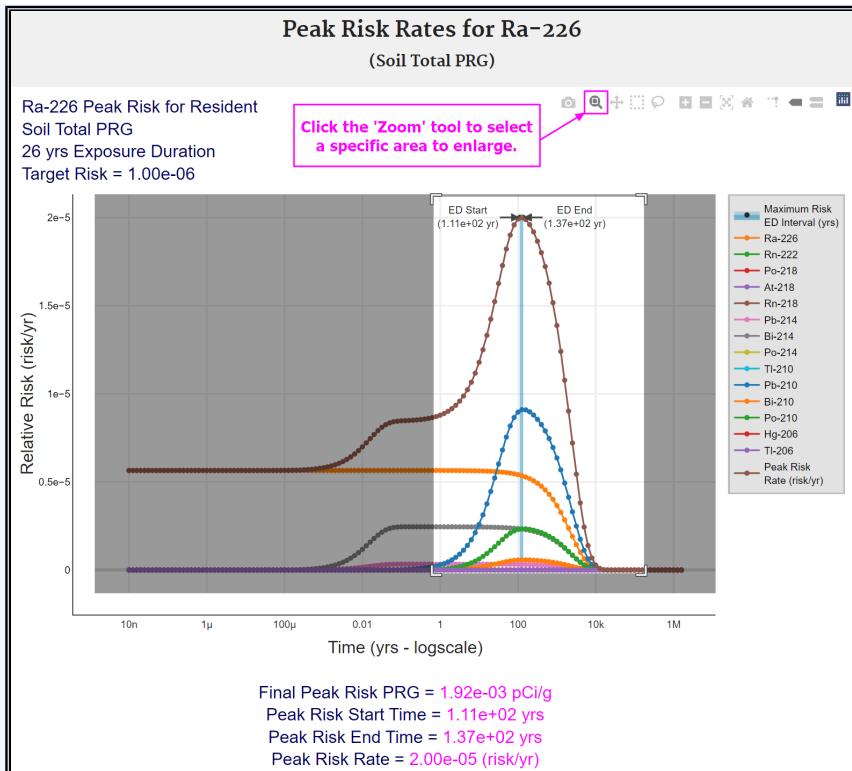
The user may also select a defined time period to search for the period of peak risk. This option operates just like the infinite time option but stops searching for the period of peak risk at a user-defined time in the future. Predefined time points of 10,000, 1,000, and 100 years are offered as well as the option for the user to enter a specific time period between 70 and one trillion years. These options are only offered for use in certain situations where a regulatory agency is concerned with risk at certain time points in the future. If a peak hasn't been resolved in the entered time period, as is the case when progeny are still ingrowing, the risk interval will be calculated for the last exposure duration span. For instance, if the time period of 100 years is selected for default resident soil for U-238 (ED of 26 years), years 74 to 100 will be selected by default, because U-238 peak risk isn't until year 3,981,072.

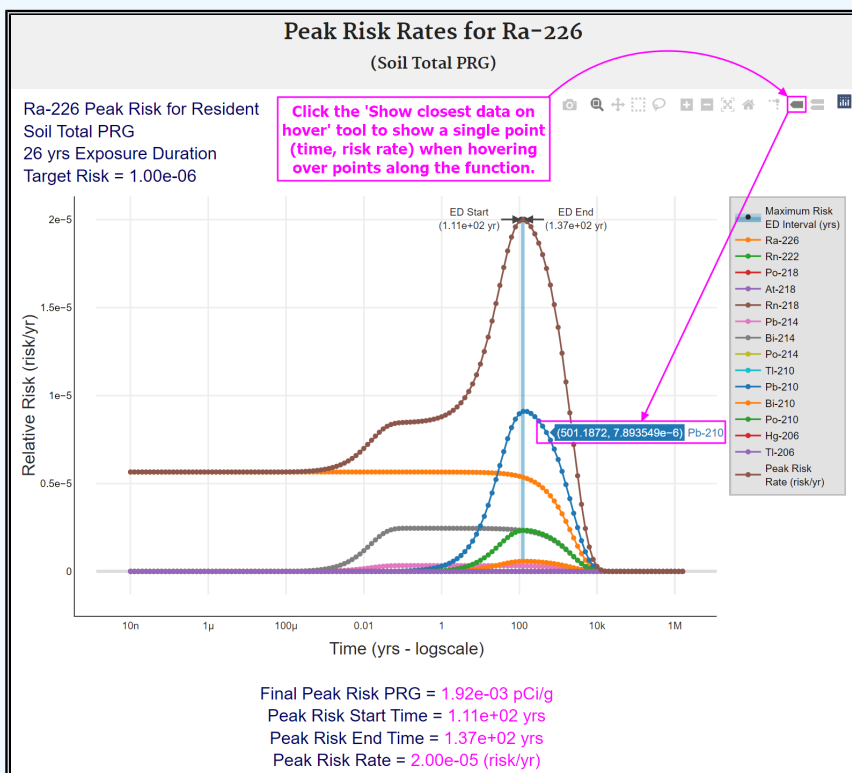
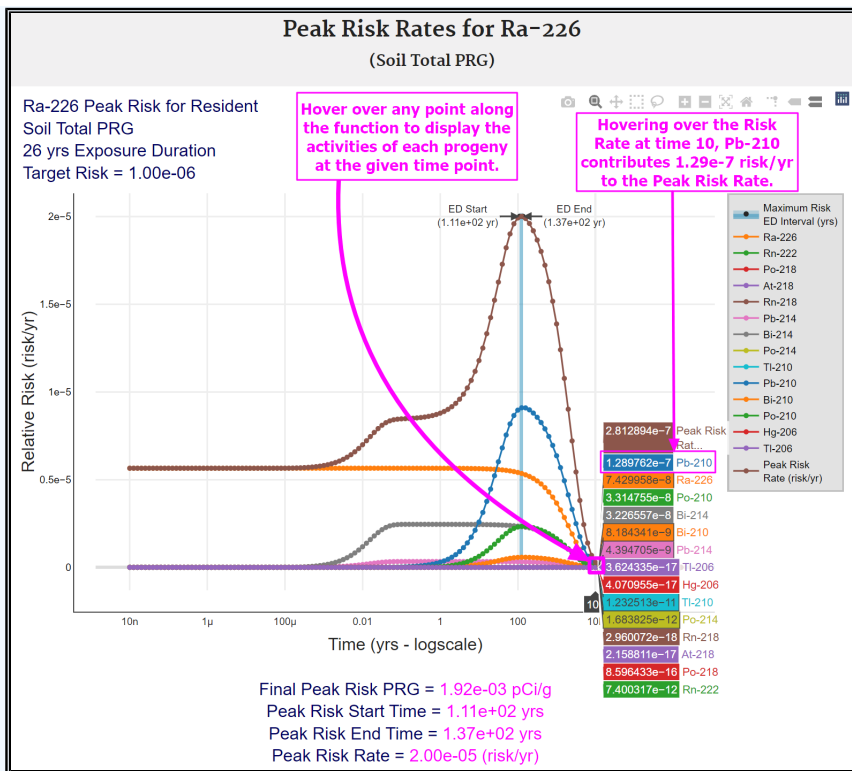
User-defined time periods should only be considered when a purified radionuclide was recently disposed or released. These time periods should not be considered when a radionuclide has been present long enough for progeny to ingrow (e.g., uranium, thorium, and radium as ore material). The default selection of infinity is the preferred option for use on Superfund sites being remediated for unrestricted future land uses.

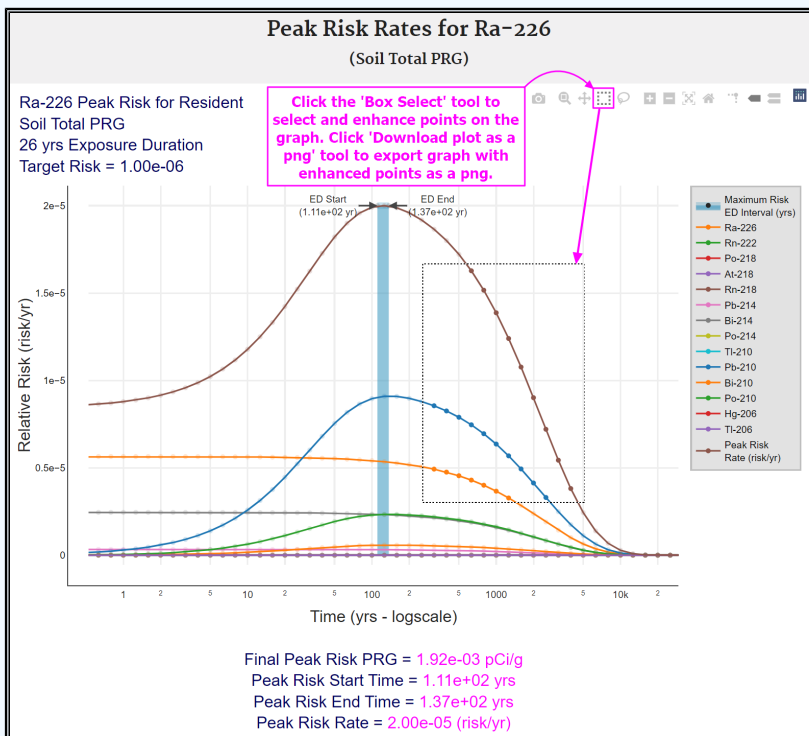
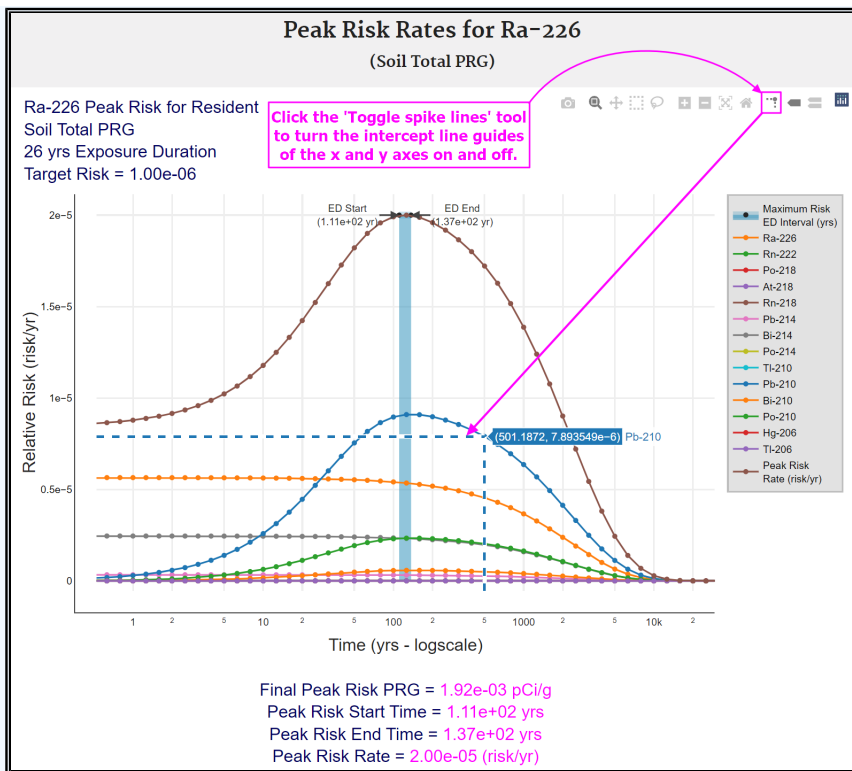
[Click Here for a Tutorial on Understanding Peak PRG Graphs](#)

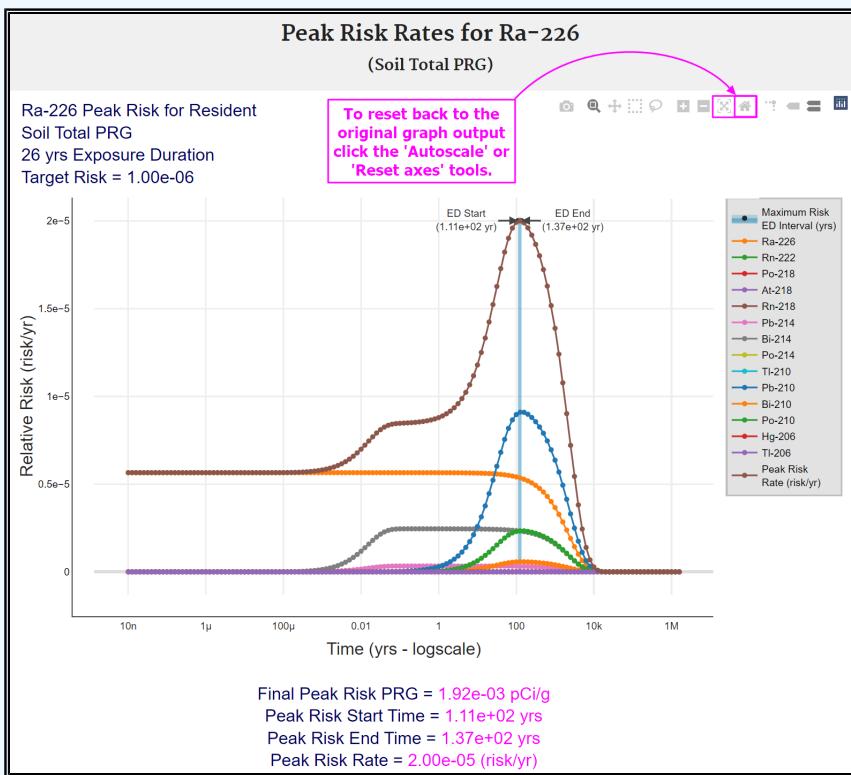
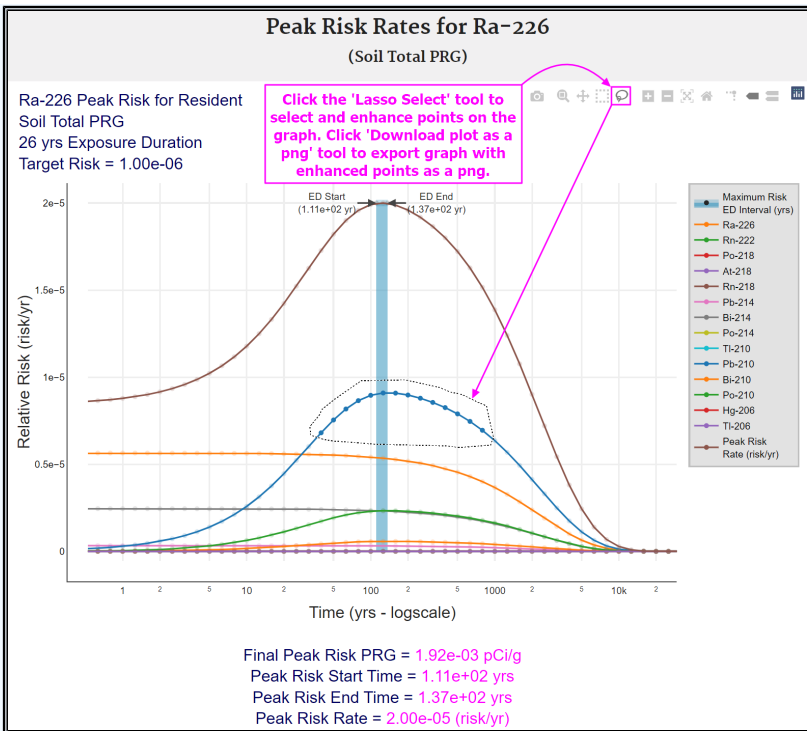
The following images provide instructions for exploring and understanding the peak risk graphs.











2.2.2 PRG Output Option #2: Assumes Secular Equilibrium Throughout the Chain (no decay - parent and progeny in constant equilibrium)

This was the default PRG calculation prior to the release of the Peak PRG. When a single isotope is selected, the calculator identifies all the progeny in the chain. The PRGs for each progeny are combined with the parent based on their FC. The FC is determined by branching fractions, where a progeny may decay into more than one isotope. The FC calculation process is described later in this section. The resulting PRG is now based on secular equilibrium of the full chain. For straight chain decay, all the progeny would be at the same activity of the parent, and the PRG provided in the output would be the inverse sum of the reciprocal PRGs of the parent and all the progeny. Unlike previous PRG output options that included progeny contribution (i.e., +D PRGs as

discussed in section 2.9.2.), the secular equilibrium PRG models each progeny independently of the parent for half-life, migration to groundwater, and biota uptake. All the soil PRG equation images are presented without a radioactive decay term. Decay is not included in this PRG option, as the assumption of secular equilibrium is that the parent is continually being renewed.

When the secular equilibrium PRG output option is selected, the PRG Calculator now gives the option to show the individual progeny contributions for the PRG (and risk) output. When the option to display progeny contribution is selected, the PRG Calculator output gives the secular equilibrium PRG and the individual progeny PRGs in separate tables.

A total PRG is calculated using the following formula:

Total secular equilibrium PRG for parent isotope;

$$PRG_{SE-tot} = \frac{1}{\left(\sum_{i=1}^n \frac{1}{PRG_{SE-route\ i}} \right)}$$

where:

n = total number of exposure routes;

Route secular equilibrium PRG for parent isotope:

$$PRG_{SE-route} = \frac{1}{\left(\sum_{i=1}^n \frac{1}{\left(\frac{PRG}{FC} \right)_i} \right)}$$

where:

n = total number of isotopes in decay chain;

FC = fractional contribution of isotope in decay chain;

PRG = PRG for isotope in decay chain without decay.

The [EPA Decay Chain tool](#) provides the branching fractions for each radionuclide's decay chain, based on the ICRP 107 data. The branching fractions presented, for non-converging chains, are used directly in the PRG equation above for the FC (fractional contribution) term. Convergence in a chain is when there are multiple decay pathways to a particular isotope or when multiple isotopes can decay to a particular isotope. When a chain converges, as is the case with the [Ra-226 chain](#), the effect of multiple branches needs to be taken into account. Consider the branching fractions in the Ra-226 decay chain in the table below.

Nuclide	Half-life	Mode	Mass	Branching Fraction	Progeny	Branching Fraction	Progeny
Ra-226	1600 years	A	226.025409	1.00e+0	Rn-222		
Rn-222	3.8235 days	A	222.017577	1.00e+0	Po-218		
Po-218	3.10 minutes	B-,A	218.008973	1.00e+0	Pb-214	2.00e-4	At-218
Pb-214	26.8 minutes	B-	213.999805	1.00e+0	Bi-214		
At-218	1.5 seconds	A,B-	218.008694	9.99e-1	Bi-214	1.00e-3	Rn-218
Bi-214	19.9 minutes	B-,A	213.998711	1.00e+0	Po-214	2.10e-4	Tl-210
Rn-218	3.50e-2 seconds	A	218.005601	1.00e+0	Po-214		
Po-214	1.64e-4 seconds	A	213.995201	1.00e+0	Pb-210		
Tl-210	1.3 minutes	B-	209.990073	1.00e+0	Pb-210		
Pb-210	22.2 years	B-,A	209.984188	1.00e+0	Bi-210	1.90e-8	Hg-206
Bi-210	5.01 days	B-,A	209.984120	1.00e+0	Po-210	1.32e-6	Tl-206

Hg-206	8.15 minutes	B-	205.977514	1.00e+0	Tl-206		
Po-210	138.38 days	A	209.982873	1.00e+0	Stable Pb-206		
Tl-206	4.2 minutes	B-	205.976110	1.00e+0	Stable Pb-206		

For example, the branching fraction presented in the above table for At-218 decaying to Rn-218 is 0.1% (0.001 or 1.0E-03); however, this isn't the complete picture, because At-218 appears in the chain as only 0.02% of Po-218 decay. To determine the true fractional contribution of Rn-218 to the whole chain, multiply the two branching fraction ratios together as follows: $2.0\text{E-}04 \times 1.0\text{E-}03 = 2.0\text{E-}07$. Technically, to calculate the fractional contribution of each isotope in a chain, each unique pathway to that isotope should have its branching fractions multiplied together and each result summed. The tables below present this process for At-218, Rn-218, Tl-210, Hg-206, and Tl-206, respectively. The FCs for the other progeny are all 1.0.

Determination of Fractional Contribution (FC) from Converging Branching Fractions in the Ra-226 Decay Chain.								
At-218 FC								
Ra-226 to Rn-222	Rn-222 to Po-218	Po-218 to At-218						Fraction
1	1	2.00E-04						2.00E-04
Total FC								2.00E-04
Rn-218 FC								
Ra-226 to Rn-222	Rn-222 to Po-218	Po-218 to At-218	At-218 to Rn-218					Fraction
1	1	2.00E-04	1.00E-03					2.00E-07
Total FC								2.00E-07
Tl-210 FC								
Ra-226 to Rn-222	Rn-222 to Po-218	Po-218 to At-218	At-218 to Bi-214	Bi-214 to Tl-210				Fraction
1	1	2.00E-04	1	2.10E-04				4.20E-08
Ra-226 to Rn-222	Rn-222 to Po-218	Po-218 to Pb-214	Pb-214 to Bi-214	Bi-214 to Tl-210				
1	1	1	1	2.10E-04				2.10E-04
Total FC								2.10E-04
Hg-206 FC								
Ra-226 to Rn-222	Rn-222 to Po-218	Po-218 to At-218	At-218 to Rn-218	Rn-218 to Po-214	Po-214 to Pb-210	Pb-210 to Hg-206		Fraction
1	1	2.00E-04	1.00E-03	1	1	1.90E-08		3.8E-15
Ra-226 to Rn-222	Rn-222 to Po-218	Po-218 to At-218	At-218 to Bi-214	Bi-214 to Po-214	Po-214 to Pb-210	Pb-210 to Hg-206		
1	1	2.00E-04	1	1	1	1.90E-08		3.8E-12
Ra-226 to Rn-222	Rn-222 to Po-218	Po-218 to At-218	At-218 to Bi-214	Bi-214 to Tl-210	Tl-210 to Pb-210	Pb-210 to Hg-206		
1	1	2.00E-04	1	1	1	1.90E-08		3.8E-12

Rn-222	Po-218	At-218	Bi-214	Tl-210	Pb-210	Hg-206		
1	1	2.00E-04	1	1	1	1.90E-08		3.8E-12
Ra-226 to Rn-222	Rn-222 to Po-218	Po-218 to Pb-214	Pb-214 to Bi-214	Bi-214 to Po-214	Po-214 to Pb-210	Pb-210 to Hg-206		
1	1	1	1	1	1	1.90E-08		1.90E-08
Ra-226 to Rn-222	Rn-222 to Po-218	Po-218 to Pb-214	Pb-214 to Bi-214	Bi-214 to Tl-210	Tl-210 to Pb-210	Pb-210 to Hg-206		
1	1	1	1	2.10E-04	1	1.90E-08		3.99E-12
Total FC								1.90E-08
TI-206 FC								
Ra-226 to Rn-222	Rn-222 to Po-218	Po-218 to At-218	At-218 to Rn-218	Rn-218 to Po-214	Po-214 to Pb-210	Pb-210 to Bi-210	Bi-210 to Tl-206	Fraction
1	1	2.00E-04	1.00E-03	1	1	1.00E+00	1.32E-06	2.64E-13
Ra-226 to Rn-222	Rn-222 to Po-218	Po-218 to At-218	At-218 to Rn-218	Rn-218 to Po-214	Po-214 to Pb-210	Pb-210 to Hg-206	Hg-206 to Tl-206	
1	1	2.00E-04	1.00E-03	1	1	1.90E-08	1.00E+00	3.80E-15
Ra-226 to Rn-222	Rn-222 to Po-218	Po-218 to At-218	At-218 to Bi-214	Bi-214 to Po-214	Po-214 to Pb-210	Pb-210 to Bi-210	Bi-210 to Tl-206	
1	1	2.00E-04	1	1	1	1.00E+00	1.32E-06	2.64E-10
Ra-226 to Rn-222	Rn-222 to Po-218	Po-218 to At-218	At-218 to Bi-214	Bi-214 to Po-214	Po-214 to Pb-210	Pb-210 to Hg-206	Hg-206 to Tl-206	
1	1	2.00E-04	1	1	1	1.90E-08	1.00E+00	3.80E-12
Ra-226 to Rn-222	Rn-222 to Po-218	Po-218 to At-218	At-218 to Bi-214	Bi-214 to Tl-210	Tl-210 to Pb-210	Pb-210 to Bi-210	Bi-210 to Tl-206	
1	1	2.00E-04	1	2.10E-04	1	1.00E+00	1.32E-06	5.54E-14
Ra-226 to Rn-222	Rn-222 to Po-218	Po-218 to At-218	At-218 to Bi-214	Bi-214 to Tl-210	Tl-210 to Pb-210	Pb-210 to Hg-206	Hg-206 to Tl-206	
1	1	2.00E-04	1	2.10E-04	1	1.90E-08	1.00E+00	7.98E-16
Ra-226 to Rn-222	Rn-222 to Po-218	Po-218 to Pb-214	Pb-214 to Bi-214	Bi-214 to Po-214	Po-214 to Pb-210	Pb-210 to Bi-210	Bi-210 to Tl-206	
1	1	1	1	1	1	1.00E+00	1.32E-06	1.32E-06
Ra-226 to Rn-222	Rn-222 to Po-218	Po-218 to Pb-214	Pb-214 to Bi-214	Bi-214 to Po-214	Po-214 to Pb-210	Pb-210 to Hg-206	Hg-206 to Tl-206	
1	1	1	1	1	1	1.90E-08	1.00E+00	1.90E-08
Ra-226 to Rn-222	Rn-222 to Po-218	Po-218 to Pb-214	Pb-214 to Bi-214	Bi-214 to Tl-210	Tl-210 to Pb-210	Pb-210 to Bi-210	Bi-210 to Tl-206	

1	1	1	1	2.10E-04	1	1.00E+00	1.32E-06	2.77E-10
Ra-226 to Rn-222	Rn-222 to Po-218	Po-218 to Pb-214	Pb-214 to Bi-214	Bi-214 to Tl-210	Tl-210 to Pb-210	Pb-210 to Hg-206	Hg-206 to Tl-206	
1	1	1	1	2.10E-04	1	1.90E-08	1.00E+00	3.99E-12
Total FC								1.34E-06

2.2.3 PRG Output Option #3: Does Not Assume Secular Equilibrium, Provides Results for Progeny Throughout Chain (with decay where appropriate)

This option displays the PRGs calculated with half-life decay that accounts for half-lives shorter than the exposure duration. See section 4.10.7 to learn more about the half-life decay function. In addition to the selected isotope, all the individual progeny PRGs are displayed. Each PRG is determined with each isotope's respective half-life and not that of its parent isotope. This option does not assume secular equilibrium and presents all the individual progeny PRGs, so that the risk assessor can identify any isotopes that will be present and those that have no data. Users can alter progeny half-life to match the parent isotope or other progeny or to account for ingrowth and decay over a chain. The individual isotope PRGs then would be combined (using the inverse sum of reciprocals method described in section 2.9.2) to give a parent PRG protective of progeny ingrowth.

2.2.4 PRG Output Option #4: Does Not Assume Secular Equilibrium, Selected Isotopes Only (with decay where appropriate)

This option displays PRGs for only the selected isotopes with half-life decay that accounts for half-lives shorter than the exposure duration. See section 4.10.7 to learn more about the half-life decay function. In this output, secular equilibrium is not assumed, progeny PRGs are not displayed, and progeny contribution is not combined into the PRG for the selected isotope. This option is useful when contamination is from one radionuclide with a very long half-life, where secular equilibrium would be too conservative.

2.2.5 Comparison of Peak PRG to the other 3 PRG Output Options

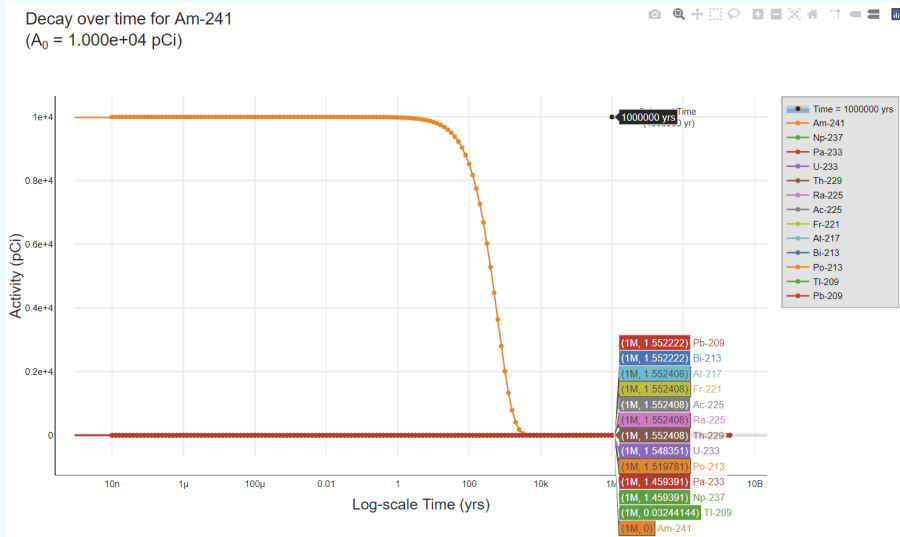
The Peak PRG output option returns results that are similar to one of the three other output options, depending upon the selected isotopes. For example, some transuranic isotopes (TRUs), such as Pu-238, Pu-239, Pu-240, and Am-241, have relatively short half lives in comparison to subsequent progeny. In such cases, equilibrium is not achieved. The activity of the relatively long-lived progeny grows in slowly, in some cases taking thousands of years to reach a significant fraction of the total activity. Furthermore, the activity of the progeny only reaches a small fraction of the parent's initial activity. For example, U-234 reaches a maximum activity of about 0.04 percent of the initial Pu-238 activity at approximately 1000 years. As such, the PRG for the parent only option is very similar to that of the Peak PRG option.

Conversely, secular equilibrium (SE) only occurs when the half-life of the progeny is much shorter than the half-life of the parent. When the progeny has a longer half-life than the parent, equilibrium does not exist. The assumption of SE in these cases significantly overestimates the activity of the progeny, resulting in a much lower PRG.

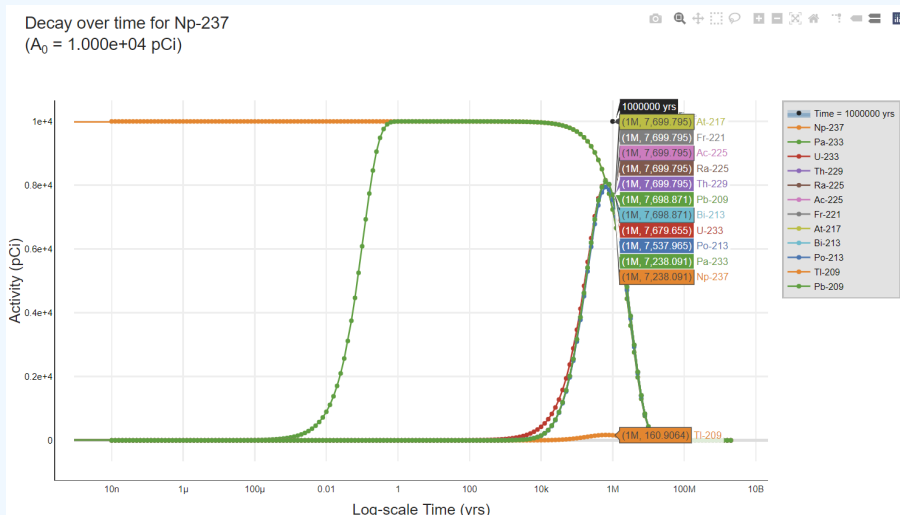
The following table presents a comparison of the default composite worker soil PRG options for Pu-238, Pu-239, Pu-240, and Am-241 and their long-lived progeny U-234, U-235, U-236, and Np-237, respectively. This table shows that each parent has a half-life about four orders of magnitude shorter than its progeny. As expected, of the three PRG options presented, the SE PRG is always the most protective (smallest). For the TRU isotopes, the peak and the parent only PRGs are shown to be essentially identical, and for the long-lived progeny, the SE and Peak PRG are more closely related. Also of interest is that the SE PRGs for the TRU isotopes and their long-lived progeny are very similar but slightly more protective than the TRU isotope PRGs. This is expected, as the risk contribution to the parent PRG is only different by one isotope in a long chain.

Isotope	Half-life (years)	Parent only PRG (pCi/g)	SE PRG (pCi/g)	Peak PRG (pCi/g)
Transuranics With Relative Short Half-lives Compared to Progeny				
Am-241	4.32E+02	4.67E+00	8.40E-02	4.67E+00
Pu-238	8.77E+01	1.41E+01	2.02E-02	1.41E+01
Pu-239	2.41E+04	1.22E+01	7.27E-02	1.22E+01

Pu-240	6.56E+03	1.23E+01	1.52E-02	1.23E+01
Long-lived Progeny of Transuranics Above, Respectively				
Np-237	2.14E+06	3.06E+00	8.56E-02	1.05E-01
U-234	2.46E+05	2.78E+01	2.03E-02	3.42E-02
U-235	7.04E+08	3.15E-01	7.31E-02	7.31E-02
U-238	2.34E+07	3.02E+01	1.53E-02	9.25E+00



The above figure shows a decay curve for Am-241 over one million years with an initial activity of 10,000 pCi. The progeny levels are near zero because the first progeny is long-lived relative to the parent. The figure below is for Np-237, the first progeny of Am-241, which has a half-life approximately four orders of magnitude longer than its parent. In the figure below, the initial activity was also 10,000 pCi. At 1 million years, the progeny activity is approximately four orders of magnitude higher than the Am-241 decay curve. This analysis demonstrates the reason the Peak PRG is similar to the parent only PRG for these transuranics with short half-lives relative to their progeny.



To further evaluate the Peak PRG option, the table below presents the three PRG output options for the common Superfund nuclides, in an effort to categorize the decay characteristics. The table presents the default composite worker soil PRGs at a target risk of 1E-06. Several categories are identified.

- Category 1: TC-99 and I-129 make up the first category, where the decay is straight to stable over a period of time much greater than the exposure duration (ED). In this case, all three PRG output options return the same value.

- Category 2: H-3 and Co-60 make up the second category, where the decay is also straight to stable, but the half-life is a fraction of the ED. In this case, the Peak PRG matches the parent-only PRG and the SE PRG is overprotective.
- Category 3: U-235, U-238, and Th-232 make up the third category, where the decay chain is long and the parent half-life is much longer than the progeny. In this case, the Peak PRG matches the SE PRG and the parent only PRGs are under protective.
- Category 4: U-234, Ra-226, Ra-228, Sr-90, Cs-137, Th-228, and Th-230 comprise the fourth category, where the SE PRGs and the Peak PRGs are much closer than the Peak PRGs and parent-only PRGs. There are multiple reasons the parent only PRGs are under protective compared to the Peak PRGs.
- Category 5: I-131 comprises the fifth category, where the Peak PRG only matches the parent-only PRG. In this instance, there is only one progeny and both chain members have a relatively short half-life compared to ED.
- Category 6: The final category is the focus of this section and consists of the transuranic isotopes: Pu-239, Am-241, Pu-240, and Pu-238. In these instances, the parent has a short half-life relative to immediate progeny, and the Peak PRGs match the parent only PRGs.

Common Superfund Isotopes (half-life)	SE Total PRG	Parent Only Total PRG	Peak PRG Total PRG	Peak PRG = SE?	Peak PRG = Parent Only?	Percent Peak PRG larger than SE	Percent Parent-only PRG larger than Peak PRG
Category 1							
Tc-99 (0.211M years)	7.67E+02	7.67E+02	7.67E+02	Yes	Yes	0%	0%
I-129 (15.7M years)	9.23E+00	9.23E+00	9.23E+00	Yes	Yes	0%	0%
Category 2							
H-3 (12.3 years)	1.61E-01	2.99E-01	2.99E-01	No	Yes	86%	0%
Co-60 (5.27 years)	1.42E-02	4.83E-02	4.83E-02	No	Yes	240%	0%
Category 3							
U-235 (704M year)	7.31E-02	3.15E-01	7.31E-02	Yes	No	0%	331%
U-238 (4.47B years)	2.00E-02	3.12E+01	2.00E-02	Yes	No	0%	155900%
Th-232 (14.1B years)	1.53E-02	1.70E+01	1.53E-02	Yes	No	0%	111011%
Category 4							
U-234 (0.246M years)	2.03E-02	2.78E+01	3.42E-02	Nearly	No	68%	81187%
Ra-226 (1600 years)	2.03E-02	3.05E+00	2.08E-02	Nearly	No	2.5%	14563%
Ra-228 (5.75 years)	1.53E-02	7.50E+00	4.92E-02	Nearly	No	222%	15144%
Sr-90 (28.8 years)	6.76E+00	3.84E+01	9.00E+00	Nearly	No	33%	327%
Cs-137 (30.2 years)	6.90E-02	5.71E+01	9.07E-02	Nearly	No	31%	62855%

Th-228 (1.91 years)	2.38E-02	1.07E+02	2.16E-01	Nearly	No	808%	49437%
Th-230 (75400 years)	2.03E-02	1.78E+01	2.20E-02	Nearly	No	8%	80809%
Category 5							
I-131 (0.022 years)	1.09E-01	8.62E+01	8.62E+01	No	Yes	78983%	0%
Category 6							
Pu-239 (24100 years)	7.27E-02	1.22E+01	1.22E+01	No	Yes	16681%	0%
Am-241 (432 years)	8.40E-02	4.67E+00	4.67E+00	No	Yes	5460%	0%
Pu-240 (6560 years)	1.52E-02	1.23E+01	1.23E+01	No	Yes	80821%	0%
Pu-238 (87.7 years)	2.02E-02	1.41E+01	1.41E+01	No	Yes	69702%	0%

*PRGs presented in this table are for TR = 1.0E-06 (pCi/g).

2.2.6 PRG output options and media that use decay

As stated in section 2.2.1, a Bateman solver is used to calculate decay and ingrowth as part of the Peak PRG model. Also, as stated in section 2.2.2, decay is not included in the secular equilibrium output because it is assumed that the parent is continually being renewed. The other 2 output options, described in sections 2.2.3 and 2.2.4, apply the decay function according to the table below. See section 4.10.7 to learn more about the half-life decay function used for the last 2 output options.

Media	Is decay applied?
Soil (soil and 2D)	Yes
Air	With and without decay options are presented
Water (surface, tap, & soil to groundwater)	No
Biota-Direction Ingestion	No

2.3 Slope Factors (SFs)

EPA classifies all radionuclides as Group A carcinogens ("carcinogenic to humans"). Group A classification is used only when there is sufficient evidence from epidemiologic studies to support a causal association between exposure to the agents and cancer. The [appendix radionuclide table](#), from the [Center for Radiation Protection Knowledge](#), lists ingestion, inhalation, and external exposure cancer slope factors (risk coefficients for total cancer morbidity) for radionuclides in conventional units of picocuries (pCi). Ingestion and inhalation slope factors are central estimates in a linear model of the age-averaged, lifetime attributable radiation cancer incidence (fatal and nonfatal cancer) risk per unit of activity inhaled or ingested, expressed as risk/pCi. External exposure slope factors are central estimates of lifetime attributable radiation cancer incidence risk for each year of exposure to external radiation from photon-emitting radionuclides distributed uniformly in a thick layer of soil, expressed as risk/yr per pCi/gram soil. External exposure slope factors can also be used that have units of risk/yr per pCi/cm² soil. When combined with site-specific media concentration data and appropriate exposure assumptions, slope factors can be used to estimate lifetime cancer risks to members of the general population due to radionuclide exposures. EPA currently provides guidance on inhalation risk assessment in [RAGS Part F](#) (Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual, Part F, Supplemental Guidance for Inhalation Risk Assessment). This guidance only addresses chemicals. The development of

inhalation slope factors for radionuclides differs from the guidance presented in RAGS Part F for development of inhalation unit risk (IUR) values for chemicals.

The SFs from the [Center for Radiation Protection Knowledge](#) differ from the values presented in [HEAST](#). The SFs were calculated using ORNL's DCAL software in the manner of Federal Guidance Report 12 and 13. For the calculation of soil ingestion slope factors, a standard soil density of 1.6 g/cm³ has been used. The radionuclides presented are those provided in the International Commission on Radiological Protection (ICRP) [Publication 107](#). This document contains a revised database of nuclear decay data (energies and intensities of emitted radiations, physical half-lives, and decay modes) for 1,252 naturally occurring and man-made radionuclides. ICRP Publication 107 supersedes the previous database, ICRP Publication 38, published in 1983.

Inhalation risk and dose coefficients for Rn-222, Rn-220, Bi-212, Bi-214, Pb-212, Pb-214, and Po-218 were updated in January 2017 and can be found [here](#). The updated values are for inhalation of individual radionuclides without accompanying progeny but include the contribution to risk from ingrowth of radioactive progeny in the body following intake of a parent radionuclide. This approach allows the user to derive cancer risk and effective dose estimates for any known or hypothetical combination of Rn-222 or Rn-220 and its short-lived progeny in air. Rn-219 is not included in the update due to the large uncertainty in the distribution of decays of Rn-219 and its progeny in the body.

2.3.1 Metastable Isotopes

Most dose and risk coefficients are presented for radionuclides in their ground state. In the decay process, the newly formed nucleus may be in an excited state and emit radiation (e.g., gamma rays) to lose the energy of the state. The excited nucleus is said to be in a metastable state, which is denoted by the chemical symbol and atomic number appended by "m" (e.g., Ba-137m). If additional higher energy metastable states are present, then "n", "p", ... is appended. Metastable states have different physical half-lives and emit different radiations and thus unique dose and risk coefficients. In decay data tabulations of [ICRP 107](#), if the half-life of a metastable state was less than 1 minute, then the radiations emitted in de-excitation are included with those of the parent radionuclide. Click to see a graphical representation of the decay of [Cs-137 to Ba-137](#).

Eu-152, in addition to its ground state, has two metastable states: Eu-152m and Eu-152n. The half-lives of Eu-152, Eu-152m, and Eu-152n are: 13.5 y, 9.31 m and 96 m, respectively, and the energy emitted per decay is 1.30 MeV, 0.080 MeV, and 0.14 MeV, respectively.

2.4 Radionuclide-Specific Parameters

Several radionuclide-specific parameters are needed for development of the PRGs. The parameters are selected from a hierarchy of sources.

2.4.1 Sources

Many sources are used to populate the database of radionuclide-specific parameters. They are briefly described below.

1. [IAEA TRS 472 \(IAEA\)](#). Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments. Technical Reports Series No. 472. International Atomic Energy Agency, Vienna. 2010. [IAEA TRS 364. Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments (Technical Reports Series No. 364), 1994 was used to supplement egg, poultry and swine transfer factors.] [Spreadsheet of values](#).
2. [Environment Agency \(EA\)](#). Initial radiological assessment methodology - part 2 methods and input data. [Spreadsheet of values](#).
3. [NCRP 123 \(NCRP\)](#). NCRP Report No. 123, Screening Models for Releases of Radionuclides to the Atmosphere, Surface Water, and Ground. National Council on Radiation Protection and Measurements. January 22, 1996. [Spreadsheet of values](#).
4. [EPA Radionuclide Soil Screening Level \(SSL\)](#). Soil Screening Guidance for Radionuclides: User's Guide. Office of Solid Waste and Emergency Response (OSWER) Directive 9355.4-16A. October 2000. [Spreadsheet of values](#).
5. [RESRAD](#). User's Manual for RESRAD Version 6. Environmental Assessment Division, Argonne National Laboratory. July 2001. [Spreadsheet of values](#).
6. [BAES](#). A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture. C. F. Baes III, R. D. Sharp, A. L. Sjoreen, R.W. Shor. Oak Ridge National Laboratory 1984. [Spreadsheet of values](#).
7. [ICRP 107](#). Nuclear Decay Data for Dosimetric Calculations. International Commission on Radiological Protection Publication 107. Ann. ICRP 38 (3), 2008.

8. **EPAKD**. Understanding Variation in Partition Coefficient, K_d , Values. Volume II: Review of Geochemistry and Available K_d Values for Cadmium, Cesium, Chromium, Lead, Plutonium, Radon, Strontium, Thorium, Tritium (3H), and Uranium. Office of Air and Radiation. EPA 402-R-99-004B. August 1999. Volume III: Review of Geochemistry and Available K_d Values for Americium, Arsenic, Curium, Iodine, Neptunium, Radium, and Technetium. Office of Air and Radiation. EPA 402-R-04-002C. July 2004. [Spreadsheet of values](#).

2.4.2 Hierarchy by Parameter

Generally the hierarchies below are followed.

1. Half-life (yr), Decay mode, Atomic weight, Atomic number and Decay energy. [ICRP 107](#).
2. 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).
3. 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).
4. Fin Fish bioconcentration factor (BCF (L/kg)). IAEA, EA, RESRAD. BCF is the ratio of the radionuclide concentration in the fin fish tissue (pCi/kg fresh weight) from all exposure pathways relative to that in water (pCi/L).
5. Shellish bioconcentration factor (BCF (L/kg)). IAEA. BCF is the ratio of the radionuclide concentration in the shellfish tissue (pCi/kg fresh weight) from all exposure pathways relative to that in water (pCi/L).
6. 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).
7. 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).
8. 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).
9. Sheep Milk transfer factor ($TF_{\text{sheep-milk}}$ (day/L)). IAEA. $TF_{\text{sheep-milk}}$ is the volumetric activity density in sheep milk (pCi/L) divided by the daily intake of radionuclide (pCi/day).
10. 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).
11. Goat Milk transfer factor ($TF_{\text{goat-milk}}$ (day/L)). IAEA. $TF_{\text{goat-milk}}$ is the volumetric activity density in goat milk (pCi/L) divided by the daily intake of radionuclide (pCi/day).
12. 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).
13. 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 (pCi/L) of the specified liquid phase).
14. 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.
 - o For carbon, the only value in the hierarchy is found in RESRAD. This value is excluded, as it overestimates root uptake. See section 2.5.4 for a detailed discussion of the carbon transfer factor derivation.
15. 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.
 - o For carbon, the only value in the hierarchy is found in RESRAD. This value is excluded, as it overestimates root uptake. See section 2.5.4 for a detailed discussion of the carbon transfer factor derivation.

Bv_{wet} and Bv_{dry} can be determined using the following equations.

$$Bv_{\text{wet}} = Bv_{\text{dry}} \times \left(\frac{100 - MC}{100} \right)$$

where:

MC = percent moisture content (%)

and:

$$Bv_{dry} = Bv_{wet} \times \left(\frac{100}{100 - MC} \right)$$

where:

MC = percent moisture content (%)

2.5 Biota Modeling

2.5.1 Produce Modeling

There are 23 individually calculated PRGs that make up the default produce PRG. The 23 individual fruits and vegetables, as well as animal products selected for use in the PRG calculator, have ingestion rates for homegrown biota in the Exposure Factors Handbook (EFH). Each individual PRG is determined based on produce-specific data, such as intake rate, soil-to-plant transfer factors (Bv_{wet}), and soil mass loading factor (MLF). These 23 individual PRGs are then summed by inverse reciprocal to determine a total produce PRG. The MLFs and intake rates used in the determination of the default biota PRGs are based on fresh weight. Intake rates, MLFs, and transfer factors were updated in June 2021 in a revised Technical Memorandum. The final version of this document was published in September 2021 and may be found [here](#).

2.5.1.1 Intake Rates (g/day)

Table 2.5.1-A provides all of the default produce intake rates that are used to determine the total produce PRG. The delineation of (FW) in the column header indicates that the intake rates are for fresh weight; these are the intake rates used when the tool is run in default mode. In site-specific mode, the user may choose between Fresh Weight (FW) or Cooked Weight (CPW), which takes cooking and preparation loss into account. In addition, the user may also add rice and cereal grain to the produce output. These intake rates can be found in Table 2.5.1-B below and are only given in dry weight (DW). In user-provided mode, the user may change produce-specific and element-specific parameters to model produce that is not provided in this tool, such as soil-to-plant transfer factor, mass loading factor, contaminated fraction, and intake rates.

In addition, a local food survey can be conducted. Much of the methodology in the [Guidance for Conducting Fish and Wildlife Consumption Surveys](#) may be useful for surveying produce consumption to determine site-specific food intake rates. Another potential source for intake rates, particularly for food exposures not included in the Exposure Factors Handbook, is the [Food Commodity Intake Database](#) (FCID). If the FCID is used, the user must convert the data to g/day, as it is required for use in this tool.

To determine which produce are commonly cultivated in the area around the site, users should contact their county extension office. The [National Pesticide Information Center](#) has an interactive map that allows users to choose their state and county and then connects them to their county extension office.

Table 2.5.1-A	Intake Rate for Farmer Child (g/day) (FW)	Intake Rate for Farmer Adult (g/day) (FW)	Intake Rate for Resident Child (g/day) (FW)	Intake Rate for Resident Adult (g/day) (FW)	Intake Rate for Farmer Child (g/day) (CPW)	Intake Rate for Farmer Adult (g/day) (CPW)	Intake Rate for Resident Child (g/day) (CPW)	Intake Rate for Resident Adult (g/day) (CPW)
Apples	82.7	84.8	72.0	73.9	42.9	44.0	37.3	38.3
Citrus	206.0	306.5	206.0	306.5	106.8	158.9	106.8	158.9
Berries other than Strawberries	24.2	35.2	24.2	35.2	12.5	18.2	12.5	18.2
Peaches	98.2	103.1	110.2	115.7	50.9	53.5	57.1	60.0
Pears	79.6	59.8	69.4	52.1	41.3	31.0	36.0	27.0

Strawberries	27.5	40.6	27.5	40.6	14.2	21.1	14.2	21.1
Asparagus	11.9	40.1	11.9	40.1	8.1	27.4	8.1	27.4
Beets	6.0	34.4	6.0	34.4	4.1	23.5	4.1	23.5
Broccoli	14.8	34.1	13.2	30.5	10.1	23.3	9.0	20.8
Cabbage	11.0	79.5	11.8	85.1	7.5	54.3	8.0	58.1
Carrots	13.1	24.4	14.5	27.1	8.9	16.6	9.9	18.5
Corn	31.6	82.1	23.2	60.2	21.6	56.1	15.8	41.1
Cucumbers	16.3	54.9	24.5	82.3	11.2	37.5	16.7	56.2
Lettuce	3.4	36.7	3.4	36.7	2.3	25.0	2.3	25.0
Lima Beans	22.0	33.9	22.0	33.9	15.0	23.2	15.0	23.2
Okra	9.4	30.4	9.4	30.4	6.4	20.8	6.4	20.8
Onions	7.5	27.3	5.9	21.5	5.1	18.6	4.0	14.7
Peas	20.4	31.6	22.6	35.0	13.9	21.6	15.5	23.9
Peppers	7.4	23.9	5.9	19.1	5.1	16.3	4.1	13.0
Pumpkins	21.2	63.5	21.2	63.5	14.5	43.4	14.5	43.4
Snap Beans	28.7	54.5	28.3	53.8	19.6	37.2	19.3	36.8
Tomatoes	42.2	94.0	36.0	80.1	28.9	64.2	24.6	54.7
White Potatoes	52.4	141.8	47.3	127.8	35.8	96.9	32.3	87.3

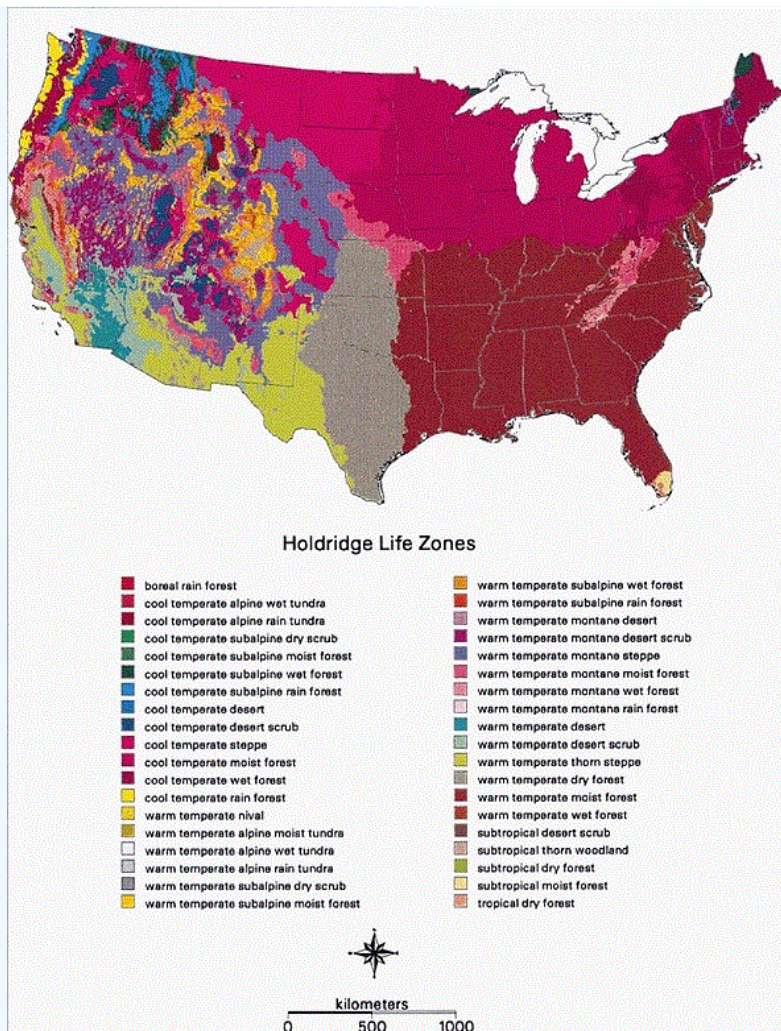
Table 2.5.1-B	Intake Rate for Farmer Child (g/day) (DW)	Intake Rate for Farmer Adult (g/day) (DW)	Intake Rate for Resident Child (g/day) (DW)	Intake Rate for Resident Adult (g/day) (DW)
Rice	49.6	98.9	41.0	81.9
Cereal Grain	48.1	84.8	39.8	70.2

2.5.1.2 Soil-to-Plant Transfer Factors (B_{wet})

The new soil-to-plant transfer factors (B_{wet}) from IAEA ([TRS-472](#)) are unique to climate zone, soil type, and produce type. There are three climate zones (Temperate, Tropical, and Subtropical), seven soil types (Default, Sand, Loam, Clay, Organic, Coral Sand, and Other), and 25 produce types implemented in the PRG calculator. When the tool is run in default mode, the climate zone is temperate, the soil type is Default (which applies to all soil types), and 23 produce types are used. Corn and rice are not used in default mode because the parameters used for these are based on dry weight, whereas the other 23 produce are based on fresh weight. For rice, IAEA did not specify a particular climate zone; therefore, the rice transfer factors have been applied to all three climate zones.

Climate Zones

The following map of the Holdridge Life Zones shows how the climate zones are distributed across the United States. Additionally, the [Köppen-Geiger](#) climate classification maps are available. This resource could be consulted to apply site-specific climate zone inputs for calculating PRGs and risk for ingestion of produce items. The Köppen-Geiger climate zone classification for every county in the U.S.A. is available [here](#).



[*The Holdridge life zones of the conterminous United States in relation to ecosystem mapping.](#) Journal of Biogeography, 26, 1032.

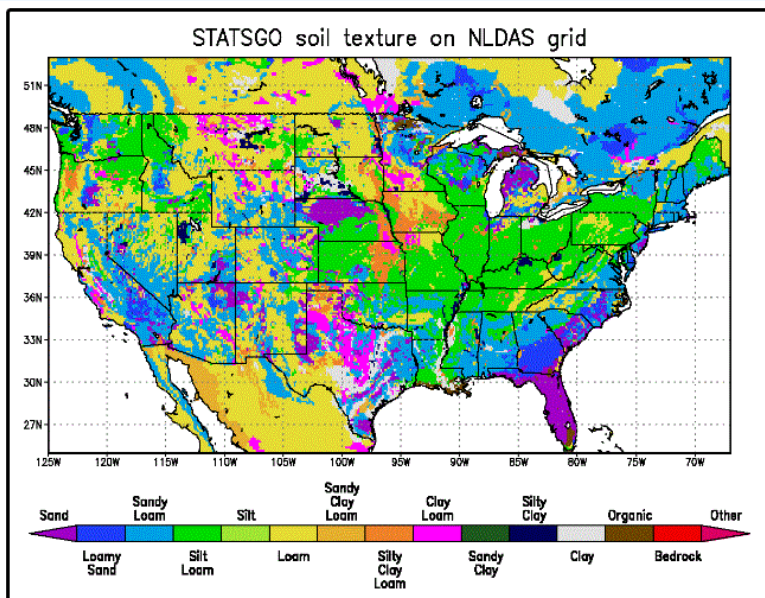
Soil Types

Table 2 below describes the soil classification used in TRS-472. The Coral Sand and Other soil types are not listed in Table 2. The 'Other' soil type classification, in a temperate climate, was created for soils without characterization data and for mineral soils with unknown sand and clay contents (TRS-472, pg. 9). For tropical climates, the 'Coral Sand' soil type classification was changed from 'Other', given in TRS-472, because it refers to soils that are outside the classification scheme used here, such as Marshall Island soils, classified by the authors as coral sand soil (TRS-472, pg. 73).

TABLE 2. TYPICAL RANGES OF VALUES OF SELECTED SOIL PARAMETERS FOR THE FOUR SOIL GROUPS

Soil group	pH	Organic matter content (%)	Cation exchange capacity (cmol _c /kg)	Sand content in the mineral matter fraction (%)	Clay content in the mineral matter fraction (%)
Sand	3.5–6.5	0.5–3.0	3.0–15.0	≥65	<18
Loam	4.0–6.0	2.0–6.5	5.0–25.0	65–82	18–35
Clay	5.0–8.0	3.5–10.0	20.0–70.0	—	≥35
Organic	3.0–5.0	≥20	20.0–200.0	—	—

[*Technical Report Series no. 472.](#)



*Land Data Assimilation Systems (LDAS). [NASA](https://www.nasa.gov/)

Produce Types

The following table illustrates which soil-to-plant transfer factor categories from IAEA are used for each produce type in the PRG calculator. The individual produce output only lists the category name from IAEA; however, a value from a secondary source may be utilized.

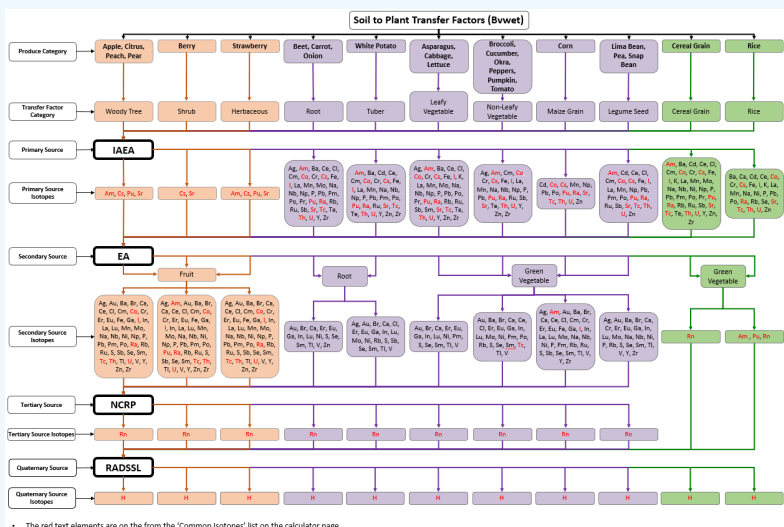
Produce Type	Primary Transfer Factor Category	Primary Transfer Factor Source	Secondary Transfer Factor Category	Secondary Transfer Factor Source	Tertiary Transfer Factor Category	Tertiary Transfer Factor Source
Apples	Woody Tree	IAEA	Fruit	EA	None	NCRP-123, RADSSL, RESRAD, and Baes
Citrus	Woody Tree	IAEA	Fruit	EA	None	NCRP-123, RADSSL, RESRAD, and Baes
Berries other than Strawberries	Shrub	IAEA	Fruit	EA	None	NCRP-123, RADSSL, RESRAD, and Baes
Peaches	Woody Tree	IAEA	Fruit	EA	None	NCRP-123, RADSSL, RESRAD, and Baes
Pears	Woody Tree	IAEA	Fruit	EA	None	NCRP-123, RADSSL, RESRAD, and Baes
Strawberries	Herbaceous	IAEA	Fruit	EA	None	NCRP-123, RADSSL, RESRAD, and Baes

Asparagus	Leafy Vegetable	IAEA	Green Vegetable	EA	None	NCRP-123, RADSSL, RESRAD, and Baes
Beets	Root	IAEA	Root Vegetable	EA	None	NCRP-123, RADSSL, RESRAD, and Baes
Broccoli	Non-Leafy Vegetable	IAEA	Green Vegetable	EA	None	NCRP-123, RADSSL, RESRAD, and Baes
Cabbage	Leafy Vegetable	IAEA	Green Vegetable	EA	None	NCRP-123, RADSSL, RESRAD, and Baes
Carrots	Root	IAEA	Root Vegetable	EA	None	NCRP-123, RADSSL, RESRAD, and Baes
Corn	Maize Grain	IAEA	Green Vegetable	EA	None	NCRP-123, RADSSL, RESRAD, and Baes
Cucumbers	Non-Leafy Vegetable	IAEA	Green Vegetable	EA	None	NCRP-123, RADSSL, RESRAD, and Baes
Lettuce	Leafy Vegetable	IAEA	Green Vegetable	EA	None	NCRP-123, RADSSL, RESRAD, and Baes
Lima Beans	Legume Seed	IAEA	Green Vegetable	EA	None	NCRP-123, RADSSL, RESRAD, and Baes
Okra	Non-Leafy Vegetable	IAEA	Green Vegetable	EA	None	NCRP-123, RADSSL, RESRAD, and Baes
Onions	Root*	IAEA	Root Vegetable	EA	None	NCRP-123, RADSSL, RESRAD, and Baes
Peas	Legume Seed	IAEA	Green Vegetable	EA	None	NCRP-123, RADSSL, RESRAD, and Baes
	Non-Leafy		Green			NCRP-123,

Peppers	Vegetable	IAEA	Vegetable	EA	None	RADSSL, RESRAD, and Baes
Pumpkins	Non-Leafy Vegetable	IAEA	Green Vegetable	EA	None	NCRP-123, RADSSL, RESRAD, and Baes
Snap Beans	Legume Seed	IAEA	Green Vegetable	EA	None	NCRP-123, RADSSL, RESRAD, and Baes
Tomatoes	Non-Leafy Vegetable	IAEA	Green Vegetable	EA	None	NCRP-123, RADSSL, RESRAD, and Baes
White Potatoes	Tuber	IAEA	Root Vegetable	EA	None	NCRP-123, RADSSL, RESRAD, and Baes
Rice	Rice	IAEA	None	NCRP-123	None	RADSSL, RESRAD, and Baes
Cereal Grain	Cereal Grain	IAEA	None	NCRP-123	None	RADSSL, RESRAD, and Baes

*The IAEA TRS-472 guidance lists onions as both root vegetables and non-leafy vegetables. The environment agency (EA), however, only lists onions as root vegetables. When the ORNL/TM-2016/328 was originally released, onion was listed as a non-leafy vegetable. For consistency with EA and due to root vegetable BVs being generally more protective, the onion BV designation was updated from non-leafy vegetable to root vegetable.

- While included in the initial hierarchy analysis, RESRAD and BAES sources do not contribute to the current output. They are retained in the user guide for informational purposes.



- Please click on flow chart to view a larger image. Carbon is missing from this chart. Please see section 2.5.4 of this user guide for information about how a soil-to-plant transfer factor was derived for Carbon in the PRG calculator.

2.5.2 Animal Product Modeling

2.5.2.1 Intake Rates (g/day)

In default mode, the (FW) intake rates from Table 2.5.2-A are used. Similar to produce, there is an option to select Cooked Weight in site-specific mode. The intake rates for poultry include chicken, turkey, and duck. In default mode, the parameters used for poultry and eggs are for chicken specifically (i.e., Q_p , etc.). If eggs and poultry are selected in site specific mode, the user will have the option to switch between chicken, turkey, duck, and goose, which will change the previously mentioned respective parameters; however, the transfer factor used will still be meant for chicken or duck per TRS-472. If the user has a specific transfer factor for turkey or goose, then user-provided mode should be used.

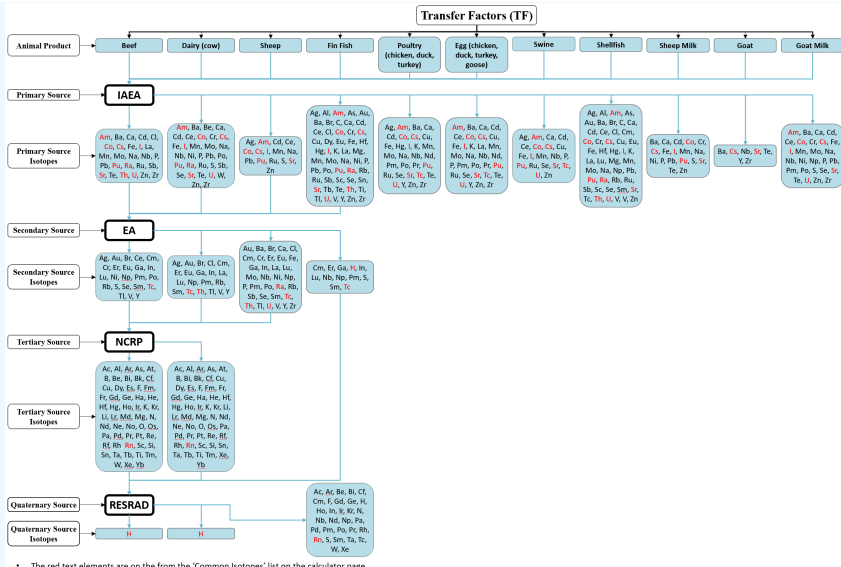
Table 2.5.2-A	Intake Rate for Farmer Child (g/day) (FW)	Intake Rate for Farmer Adult (g/day) (FW)	Intake Rate for Farmer Child (g/day) (CPW)	Intake Rate for Farmer Adult (g/day) (CPW)
Dairy - Cow	1116.4	1438.0	n/a	n/a
Beef	64.6	270.1	31.9	133.5
Swine	32.2	151.1	15.9	74.7
Poultry	48.8	175.5	24.1	86.7
Egg	25.1	97.3	n/a	n/a
Fish	36.1	155.9	22.1	95.6
Shellfish	21.3	208.9	13.0	128.1

Site-Specific mode also offers the user the option to add animal products from Table 2.5.2-B to the output. The tool has transfer factors for these products; however, the user will need to enter their own intake rate data, as the tool does not provide any. Again, a local food survey can be conducted, which may utilize much of the methodology in the [Guidance for Conducting Fish and Wildlife Consumption Surveys](#) for surveying animal product consumption to determine site-specific food intake rates. In addition, the [Food Commodity Intake Database](#) (FCID) may be used to find intake rate data, but the user must convert the data to g/day, as it is required for use in this tool.

Table 2.5.2-B	Intake Rate for Farmer Child (g/day) (FW)	Intake Rate for Farmer Adult (g/day) (FW)	Intake Rate for Farmer Child (g/day) (CPW)	Intake Rate for Farmer Adult (g/day) (CPW)
Sheep	n/a	n/a	n/a	n/a
Sheep Milk	n/a	n/a	n/a	n/a
Goat	n/a	n/a	n/a	n/a
Goat Milk	n/a	n/a	n/a	n/a

2.5.2.2 Animal Transfer Factors (TF)

- While included in the initial hierarchy analysis, RADSSL and BAES sources do not contribute to the current output. They are retained in the user guide for informational purposes. Please see section 2.4.1 for the transfer factor source hierarchy.



- Please click on flow chart to view a larger image.

2.5.3 Mass Loading Factor

A mass loading factor (MLF) is the amount, or mass, of soil that adheres to the plant surface. The following table lists the MLFs used in this tool according to plant type. For more information on how these were derived, please see the Technical Memorandum: [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: 2021 Revision.](#)

Table 2.4.3-A	Mass Loading Factor (MLF)	Units	Reference
Apples	1.60E-04	g dry soil / g fresh plant	EA (2009)
Citrus	1.57E-04	g dry soil / g fresh plant	EA (2009)
Berries other than Strawberries	1.66E-04	g dry soil / g fresh plant	EA (2009)
Peaches	1.50E-04	g dry soil / g fresh plant	EA (2009)
Pears	1.60E-04	g dry soil / g fresh plant	EA (2009)
Strawberries	8.00E-05	g dry soil / g fresh plant	EA (2009)
Asparagus	7.90E-05	g dry soil / g fresh plant	EA (2009)
Beets	1.38E-04	g dry soil / g fresh plant	EA (2009)
Broccoli	1.01E-03	g dry soil / g fresh plant	Hinton (1992), SSG-Appendix G
Cabbage	1.05E-04	g dry soil / g fresh plant	EA (2009)
Carrots	9.70E-05	g dry soil / g fresh plant	EA (2009)
Corn	1.45E-04	g dry soil / g fresh plant	Pinder & McLeod (1989), SSG-Appendix G

Cucumbers	4.00E-05	g dry soil / g fresh plant	EA (2009)
Lettuce	1.35E-02	g dry soil / g fresh plant	Hinton (1992), SSG-Appendix G
Lima Beans	3.83E-03	g dry soil / g fresh plant	Hinton (1992), SSG-Appendix G
Okra	8.00E-05	g dry soil / g fresh plant	EA (2009)
Onions	9.70E-05	g dry soil / g fresh plant	EA (2009)
Peas	1.78E-04	g dry soil / g fresh plant	EA (2009)
Peppers	2.22E-03	g dry soil / g fresh plant	EA (2009)
Pumpkins	5.80E-05	g dry soil / g fresh plant	EA (2009)
Snap Beans	5.00E-03	g dry soil / g fresh plant	Hinton (1992), SSG-Appendix G
Tomatoes	1.77E-03	g dry soil / g fresh plant	Hinton (1992), SSG-Appendix G
White Potatoes	2.10E-04	g dry soil / g fresh plant	EA (2009)
Cereal Grains	2.50E-01	g dry soil / g dry plant	Hinton (1992)
Rice	2.50E-01	g dry soil / g dry plant	Hinton (1992)
Pasture	2.50E-01	g dry soil / g dry plant	Hinton (1992)

2.5.4 Soil-to-Plant Transfer Factor Derivation for Carbon

The value of 5.5 given in Table D.3 of the RESRAD User's Manual for carbon root uptake was derived from data in Ng et al. 1968. Table 4 of Ng 1968 presents a carbon composition in typical agricultural soil of 2.00E+04 ppm and a carbon composition in terrestrial plants of 1.10E+05 ppm in Table 10A. 1.10E+05 divided by 2.00E+04 gives the value of 5.5 reported in RESRAD. This value assumes that all the carbon in the plant is taken up by the roots; however, this is not the case. Photosynthesis is the primary source of carbon in plants. Carbon may be present in gas form in soils and volatilize into the plant canopy, where it may be taken up by the plant in some fraction depending on atmospheric conditions. It is typically estimated that 2% of plant carbon comes from soil (either directly or by uptake from the sub-canopy atmosphere). The other 98% of plant carbon comes from the above-canopy atmosphere, which is assumed not to contain carbon from the contaminated site. Consider that a plant is about 90% water and of the 10% dry matter about 40% is carbon. Therefore, plants comprise about 4% carbon on a fresh weight basis. A mineral soil is typically about 2% to 5% organic matter, which corresponds to 0.8% to 2% carbon on a dry mass basis. Thus, taking the ratio of carbon contents results in a transfer factor of $4\% / (0.8\% \text{ to } 2\%) = 5.0$ to 2.0 g fresh plant/g dry soil. The next step is to apply the 2% fraction of plant carbon derived from soil. The resulting range of transfer factors is 0.1 to 0.04 ($2\% * (5.0 \text{ to } 2.0)$). The value of 0.1 is chosen for the calculation of PRGs and is used for all the BVwet values. BVdry values are derived for each plant type based on individual moisture content. For comparison purposes, the 5.5 value from RESRAD gives a transfer factor of 0.11 if the 2% assumption is made.

The above derivation assumes that all the carbon taken up by the plant is radioactive. In situations where radioactive carbon is mixing with stable carbon, a site-specific transfer factor can be derived using a model called "specific activity". Essentially, specific activity is the concentration ratio of the radioactive form to the stable form of carbon. Specific activity assumes that within a compartment (i.e., soil), the radioactive contaminant mixes with the stable form both chemically and physically. Plants uptake the element in the same ratio as it exists in the soil compartment, resulting in the

same ratio in the plant as in the soil compartment.

To determine a site-specific soil-to-plant transfer factor, actual site data must be available. Further, the flux rate of the element must be in a steady-state condition. The environmental compartments must be well defined and the fluxes between compartments well understood. For further information, refer to the following: [AMEC/004041/007](#) section 5, [ANL/EAD-4](#) Appendix L, and [IAEA TECDOC 1616](#) page 550.

2.6 PRGs in Context of Superfund Modeling Framework

This PRG calculator focuses on the application of generic and simple site-specific approaches that are part of a larger framework for calculating concentration levels for complying with risk-based criteria. Generic PRGs for a 1×10^{-6} cancer risk standard are provided by viewing either the tables in the [PRG Download Area](#) section of this calculator or by running the [PRG Calculator](#) section of this website with the "Defaults" option. Part 3 of the [Soil Screening Guidance for Radionuclides: Technical Background Document](#) provides more information about five more detailed soil-to-groundwater models that are part of the same framework.

Generic PRGs are calculated from the same equations presented in the site-specific portion of the calculator, but they are based on a number of default assumptions chosen to be protective of human health for most site conditions. Generic PRGs can be used in place of site-specific PRG levels; however, in general, they are expected to be more protective than site-specific levels. The site manager should weigh the cost of collecting the data necessary to develop site-specific PRGs with the potential for deriving a higher PRG that provides an appropriate level of protection.

The framework presented in Part 3 of the [Soil Screening Guidance for Radionuclides: Technical Background Document](#) includes more detailed modeling approaches that take into account more complex site conditions than the generic or simple site-specific methodology used for the soil-to-groundwater scenario in this calculator. More detailed approaches may be appropriate when site conditions (e.g., very deep water table, very thick uncontaminated unsaturated zone, soils underlain by karst or fractured rock aquifers) are substantially different than those assumed in the generic or simple-site methodology presented in this calculator. Further information on using more detailed approaches may be found in "[Simulating Radionuclide Fate and Transport in the Unsaturated Zone: Evaluation and Sensitivity Analyses of Select Computer Models](#)" (U.S. EPA 2002c). This report provides a detailed technical analysis of five unsaturated zone fate and transport models for radionuclides.

To avoid unnecessary inconsistency between radiological and chemical risk assessment and radiological dose assessment at the same site, users should generally use the same model for chemical and radionuclide risk assessment and radionuclide dose assessment. If there is a reason on a site-specific basis for using another model, justification for doing so should be developed. The justification should include specific supporting data and information in the administrative record. The justification normally would include the model runs using both the recommended EPA PRG model and the alternative model. Users are cautioned that they should have a thorough understanding of both the PRG recommended model and any alternative model when evaluating whether a different approach is appropriate. When alternative models are used, the user should adjust the default input parameters to be as close as possible to the PRG inputs, which may be difficult since models tend to use different definitions for parameters. Numerous computerized mathematical models have been developed by EPA and other organizations to predict the fate and transport of radionuclides in the environment; these models include single-media unsaturated zone models (for example, groundwater transport) as well as multi-media models. These models have been designed for a variety of goals, objectives, and applications; as such, no single model may be appropriate for all site-specific conditions. Generally, even when a different model is used to predict fate and transport of radionuclides through different media, EPA recommends using the PRG calculators for the remedial program to establish the risk-based concentrations to ensure consistency with CERCLA, the NCP, and EPA's Superfund guidance for remedial sites. Prior to using another model for risk assessment at a CERCLA remedial site, EPA regional staff should consult with the Superfund remedial program's National Radiation Expert (Stuart Walker, at (703) 603-8748 or walker.stuart@epa.gov). For more information on this issue, please see questions 10 and 16 on pages 12 and 17-18 of [Radiation Risk Assessment At CERCLA Sites: Q & A](#) (EPA 540-R-012-13, May 2014).

At CERCLA sites, carcinogenic risk to receptors should generally not exceed 1×10^{-4} . How that is achieved is a risk management decision that varies at different sites, which is why it is not detailed in the PRG calculator documentation. At CERCLA remedial sites, excess cancer risk from both radionuclides and chemical carcinogens should be summed to provide an estimate of the combined risk presented by all carcinogenic contaminants. For more information, see question 29 in [Radiation Risk Assessment At CERCLA Sites: Q & A](#). This document contains even more information on the CERCLA risk assessment process for radioactively contaminated sites in general, including the role of the PRG calculator. The PRG calculator is recommended by EPA to develop risk-based PRGs for Superfund remedial radiation risk

assessments.

2.7 Understanding Risk Output on the PRG Website

The PRG [calculator](#) provides an option to "Select risk output". This requires the calculator to be run in "Site Specific" mode. Note: The "Soil-to-Groundwater" medium does not have risk output, and the risk option will become disabled when selected. The risk values presented on this site are radionuclide-specific values for individual contaminants in air, water, soil, and biota that may warrant further investigation or site cleanup.

2.7.1 General Considerations for the Risk Output

The first step in the risk assessment process is hazard identification, where site data is screened against PRGs to identify radionuclides of potential concern (ROPCs). The "Risk Characterization" step, in the risk assessment process, incorporates the outcome of the exposure and toxicity assessment steps to calculate the Excess Lifetime Cancer Risk (ELCR) identified in the data screening part of the hazard identification step. ELCR is calculated for each land use determined appropriate for the site. The ELCR sum is presented for each exposure route for all ROPCs and for each ROPC across all exposure routes. The process used to calculate ELCR in this calculator follows the traditional method of first calculating a CDI (Chronic Daily Intake).

The basic equation for calculating ELCR is:

$$ELCR_{media-tot} = \sum_{i,k} (ELCR_{i,k})$$

where:
 $i = i^{th}$ route;
 $k = k^{th}$ isotope;
 $(ELCR_{route-tot})_k = \sum_i (ELCR_{i,k})$
 and:
 $(ELCR_{ROPC-tot})_i = \sum_k (ELCR_{i,k})$
 where:
 $ELCR_{i,k} = (CDI_{route} \times SF_{route})$
 where:
 $SF = \text{Slope Factor expressed in } \left[\frac{\text{risk}}{\text{pCi}}, \frac{\text{risk-g}}{\text{pCi-year}}, \frac{\text{risk-L}}{\text{pCi-year}}, \frac{\text{risk-m}^3}{\text{pCi-year}} \right]$
 $CDI = \text{Chronic Daily Intake expressed in } \left[\text{pCi}, \frac{\text{pCi-year}}{\text{g}}, \frac{\text{pCi-year}}{\text{L}}, \frac{\text{pCi-year}}{\text{m}^3} \right]$

The secular equilibrium equation for calculating ELCR is:

$$ELCR_{SE-tot} = \sum_j \left(\sum_{i,k} (ELCR_{i,k,j}) \right)$$

where:
 $i = i^{th}$ route;
 $k = k^{th}$ isotope;
 $(ELCR_{SE-route-tot})_k = \sum_j \left(\sum_i (ELCR_{i,k,j}) \right)$
 and:
 $(ELCR_{SE-ROPC-tot})_i = \sum_j \left(\sum_k (ELCR_{i,k,j}) \right)$
 where:
 $(ELCR_{i,k,j}) = (CDI_{SE-route} \times SF_{SE-route} \times FC_j)$
 where:
 $j = j^{th}$ progeny in the decay series;
 $FC = \text{fractional contribution of each progeny,}$
 $SF = \text{Slope Factor expressed in } \left[\frac{\text{risk}}{\text{pCi}}, \frac{\text{risk-g}}{\text{pCi-year}}, \frac{\text{risk-L}}{\text{pCi-year}}, \frac{\text{risk-m}^3}{\text{pCi-year}} \right]$
 $CDI = \text{Chronic Daily Intake expressed in } \left[\text{pCi}, \frac{\text{pCi-year}}{\text{g}}, \frac{\text{pCi-year}}{\text{L}}, \frac{\text{pCi-year}}{\text{m}^3} \right]$

The risk results are color coded to identify risk ranges and radionuclides of concern (ROCs). The colors and the associated risk ranges are presented in the table below.

Excess Lifetime Cancer Risk			
Risk Range	Risk < 0.000001	Risk > 0.000001	Risk > 0.0001

Color Code	No shading	Yellow	Red
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2.7.2 General Considerations for Entering Site Data

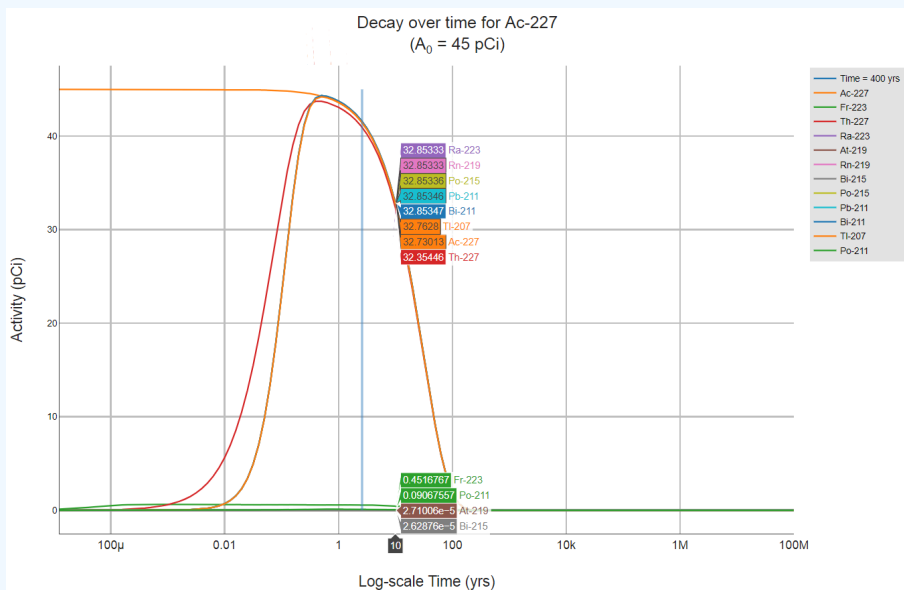
There are four calculator output options available to the user.

- PRG Output Option #1: Assumes period of peak risk (with decay and progeny ingrowth) (Peak PRG)
- PRG Output Option #2: Assumes Secular Equilibrium Throughout the Chain (no decay - parent and progeny in constant equilibrium)
- PRG Output Option #3: Does Not Assume Secular Equilibrium, Provides Results for Progeny Throughout Chain (with decay where appropriate)
- PRG Output Option #4: Does Not Assume Secular Equilibrium, Selected Isotopes Only (with decay where appropriate)

The first two options include progeny contributions in the risk calculations of the parent. The third and fourth options do not. However, if the third option is selected, the media concentrations for the progeny are automatically populated with the concentration entered for the parent. The progeny will have their risk calculated independent of each other. This autofill feature is not available when isotope chains overlap. The autofill feature is solely for convenience and does not assume secular equilibrium.

If the data is collected from a site where secular equilibrium is assumed to be present, the user need only enter the activity of the parent in the calculator, and a representative risk of the parent and all progeny will be presented in the calculator output. In the case of non-secular equilibrium, the current "state of the chain" may not be known or easily calculated. In the case of relatively fast decaying isotopes, significant decay or ingrowth of progeny may have occurred since the sample date. Further, determining future activity of the contaminants may be useful in planning for future release of a property.

A [Decay Chain Activity Projection Tool](#) has been developed, where the user can select an isotope, enter a length of time to allow decay and ingrowth, and enter the beginning activity of the parent. The results of this tool, pictured below, are the activities of the parent and progeny at the end of the decay and ingrowth of progeny time. These activities can be entered into the PRG calculator to calculate risk using the third and fourth PRG Output options.



2.7.3 One-Hit Rule

The linear risk equations, listed above, are valid only at low risk levels (below estimated risks of 0.01). For sites where radiological exposure might be high (estimated risks above 0.01), an alternate calculation should be used. The one-hit equation, which is consistent with the linear low-dose model, should be used instead ([RAGS, part A, ch. 8](#)). The one-hit rule is applied as follows:

$$ELCR = 1 - \exp(-CDI \times SF)$$

or, when necessary for tapwater inhalation:

$$ELCR = 1 - \exp(-CDI \times SF \times A_{eq})$$

The definitions for these equation parameters are provided in section 2.7.1. See section 4.10.8 for information about A_{eq} . The results presented in the PRG use this rule. In the following instances, the one-hit rule is used independently in the risk output tables:

- Risk from a single exposure route for a single radionuclide.
- Summation of single radionuclide risk (without one-hit rule applied to single radionuclide results) for multiple exposure routes (right of each row).
- Summation of risk (without one-hit rule applied to single radionuclide results) from a single exposure route for multiple radionuclides (bottom of each column).
- Summation of total risk (without one-hit rule applied to single radionuclide results or summations listed above) from multiple radionuclides across multiple exposure routes (bottom right hand cell).

2.8 Sensitivity Analysis

A sensitivity/uncertainty analysis is the quantitative assessment of how changing a single value impacts the PRG calculation. Sensitivity analyses are generally conducted to determine what variables in a PRG have the greatest impact when changed. Evaluating the uncertainty associated with a PRG calculation can identify a need for site-specific parameters. If the level of uncertainty is acceptable, then the PRGs can be used accordingly. However, if the resulting uncertainty is not acceptable, the sensitivity analysis will help to identify those parameters that, if measured on a site-specific basis, would decrease uncertainty to the greatest extent.

Examples of site-specific variables that can greatly impact a PRG are:

- soil-to-water partition coefficients,
- biota transfer factors,
- water to air volatilization,
- gamma shielding factors, and
- area correction factors

Examples of site-specific exposure parameters that can greatly impact a PRG are:

- exposure duration,
- intake rates, and
- fraction ingested of contaminated biota

The quantitative assessment of uncertainties in the transport and exposure parameters provides considerable information about the variability and sensitivity of the calculated default PRGs. These results are important because point estimates of these parameters are used to determine the extent of remediation necessary through the Superfund process. The point estimates provided as guidance by the U.S. Environmental Protection Agency (EPA) are often conservative and can result in an overestimate of the potential risk. The intent of this section is to raise awareness of the potential cost savings of developing site-specific values for key parameters. The results can be used to quantify the degree to which the standard default values overestimate the predicted percentiles of exposure (typically 90–95th percentile values) that they are intended to estimate and to determine which parameters are responsible for the majority of the variation. Please see [Guidance for Conducting Risk Assessments and Related Risk Activities for the DOE-ORO Environmental Management Program](#) for additional information.

There are several methods for identifying the most important contributors to uncertainty. Monte Carlo simulation with either Simple Random Sampling (SRS) or Latin Hypercube Sampling (LHS) is often the most robust method for propagating uncertainty through either simple or complex models. Please see [An Introductory Guide to Uncertainty Analysis in Environmental and Health Risk Assessment](#) for additional information.

Many of the PRG equations are linear, and changing a parameter has a directly proportional impact on the PRG. For example, doubling the intake rate in a fish ingestion PRG will reduce the PRG by half.

2.9 Advanced Calculator Uses (Postprocessing and Replicating Discontinued PRG Options)

The PRG [calculator](#) results, when exported in a spreadsheet, can be used to create site-specific PRGs that cannot be developed solely within the calculator. This postprocessing of results can be useful when the calculator doesn't offer the precision necessary for remedial decision. Additionally, the calculator can be used to replicate the old +D PRGs.

2.9.1 Postprocessing Calculator Results to Incorporate Site-Specific MCNP

Factors

Nearly all of the exposure parameters in the PRG equations can be changed by using the site-specific option in the calculator. Further, many of the isotope-specific values (i.e., slope factors, dose coefficients, partition coefficients, and transfer factors for plants and animals) can be changed by using the user-provided option in the calculator. While many options are given for users to select site size and clean soil cover, it may be necessary to derive a "factor" specific to a particular site using tools like Monte Carlo Nuclear Particle (MCNP). For example, a user may want to use MCNP or another tool to develop a site-specific ACF for an unusual situation (e.g., a site that consists of flat land that is next to a cliff face and both are contaminated). The following is a brief description of how to postprocess calculator results when including the results for a factor that was developed in another tool such as MCNP. All variables in the ingestion and inhalation equations can be changed in the calculator itself; the external exposure route is the most likely to require postprocessing.

The calculator offers the option to export results in a spreadsheet format. Using the spreadsheet, the "factor" supplied by the calculator can be substituted with a site-specific factor supplied by the user. The procedure is relatively straight forward, as all the factors are in the denominator of the screening level equations. Simply multiply the screening level by the ratio of the default factor to the site-specific factor.

This general process does work; but please consider the following, as further steps may be necessary:

- If adjusting a factor in the external exposure route, the total PRG needs to be recalculated using the inverse sum of reciprocals.
- If adjusting a factor in parentheses, such as a resident GSF_i, then more postprocessing is required.
- When adjusting a PRG calculated by the secular equilibrium option, factors for all the progeny need to be calculated and totaled using the inverse sum of reciprocals.
- The Peak PRG results are impossible to post process because the state of the chain (decay and ingrowth of all members) can't be replicated in a spreadsheet. Section 2.2.5 discusses what PRG output options are closest to the Peak PRG. In many cases, the parent only with decay or the SE PRGs may be identical to the Peak PRG. Post processing one of these substitute PRG options can replicate the Peak PRG results.

Here is an example of the PRG calculator default results for external (2-D soil volume) exposure for an indoor worker exposed to soil. The default GSF_i is 0.4 and represents the shielding provided by general subfloor materials from contaminated soil. In the case of a commercial building being constructed on a concrete slab, a site-specific shielding factor can be generated with MCNP and the site-specific PRG recalculated following the procedure discussed previously. Suppose a GSF_i was determined to be 0.2 with MCNP for Ra-226 without consideration of progeny. Users should note that post processing for Ra-226 would require these steps for each of the progeny with an external slope factor.

The original results are below and show a GSF_i of 0.4 (cell F5) and a PRG of 17.6 pCi/g (cell G5).

	A	B	C	D	E	F	G
1	Default						
2	Indoor Worker PRGs for 2-D Direct External Exposure - No secular equilibrium, no progeny (with decay)						
3							
		External Exposure Slope Factor (risk/yr per pCi/g)	Lambda (1/yr)	Half-life (yr)	Default Soil Volume Area Correction Factor	Total Indoor GSF_i Soil Volume	Soil Volume PRG TR=1.0E-06 (pCi/g)
4	Isotope						
5	Ra-226	2.50E-08	4.33E-04	1.60E+03	1.00E+00	4.00E-01	1.76E+01

The postprocessed results are below with a GSF_i of 0.2 (cell H5) showing the resulting site-specific PRG (cell J5) is twice as large as the default value above, as expected. The green shaded cells need to be added and programmed by the user. Below the green cells, the formula for the postprocessing procedure is given.

	A	B	C	D	E	F	G	H	I	J
1	Default									
2	Indoor Worker PRGs for 2-D Direct External Exposure - No secular equilibrium, no progeny (with decay)									
3										
		External Exposure Slope Factor (risk/yr per pCi/g)	Lambda (1/yr)	Half-life (yr)	Default Soil Volume Area Correction Factor	Total Indoor GSF _i Soil Volume	Soil Volume PRG TR=1.0E-06 (pCi/g)	Site-Specific Total Indoor GSF _i Soil Volume	Default GSF _i Removed Soil Volume PRG TR=1.0E-06 (pCi/g)	Site-Specific Soil Volume PRG TR=1.0E-06 (pCi/g)
4	Isotope									
5	Ra-226	2.50E-08	4.33E-04	1.60E+03	1.00E+00	4.00E-01	1.76E+01	2.00E-01	7.04E+00	3.52E+01
6									G5 x F5	I5 / H5

Please contact your EPA regional risk assessor before post processing PRG calculator results for Superfund sites.

2.9.2 Replicating the Old +D PRGs

Prior to 2017, "+D" designated slope factors and subsequently +D PRGs were available as the preferred PRG output option. This designation indicated that the slope factor included the contribution from ingrowth of progeny out to 100 years. Similarly, +E indicated ingrowth out to 1000 years. [HEAST](#) provided the original table of the +D radionuclide slope factors, and [ORNL 2014c](#) with [appendix](#) provides the +D slope factors previously used in this calculator. The intention of this designation was to make PRGs protective by including the contributions from their short-lived decay products that were, at times, difficult to measure. The +D designation indicated that the parent radionuclide PRG included the risk contribution from its short-lived progeny. The PRGs presented in sections 2.2.1 and 2.2.2 independently model progeny during migration to groundwater and biota uptake, while the +D PRGs did not. The use of the +D PRGs was discontinued because of the following reasons that led to imprecision in the +D PRGs:

- The half-life of the parent isotope was used for all the short-lived progeny included in the +D to calculate decay.
- The K_d of the parent was used for all the short-lived progeny in the soil-to-water partitioning PRGs to calculate downgradient water concentrations.
- The biota transfer factors for the parent was used for all the short-lived progeny included in the +D to calculate nuclide uptake into plants and animals.

The steps to replicate the old +D PRGs are as follows.

- Select the PRG output option described in section 2.2.3 (Does Not Assume Secular Equilibrium, Provides Results for Progeny Throughout Chain).
- Select Site-Specific, then User-provided on the calculator main page.
- At this point, there are three ways to proceed to calculate +D PRGs.
 - The easiest way is to just change the slope factors to the +D slope factors found in HEAST and adjust any exposure parameters. On the results page, the parent isotope PRG will be a +D PRG because +D slope factors were used.
 - Alternatively, on the Site-Specific page, every isotope-specific parameter and every exposure parameter can be changed to match the old +D PRG inputs including: half-life, K_d , biota transfer factors, gamma shielding factors, and area correction factors. Make appropriate changes to all isotopes; specifically, do not change the slope factors to +D slope factors. The results of this endeavor will be a very close approximation to the old +D PRGs.
 - Finally, if the desire is to determine what a modern version of a +D PRG would be, change nothing for any of the isotopes.
- For the second and third options above, on the results page, the individual isotope PRGs will be presented. The last step is to combine the appropriate parent and progeny PRGs to make a +D PRG. This is done by taking the inverse sum of the reciprocals of the individual PRGs. Replication of the +D PRGs for the biota route will be impossible, as the models have changed. Consult the table below to determine what progeny should be included in the summation method.

For the time-being, the [RAIS](#) Radionuclide PRG Calculator still offers +D PRGs. Below is a table of progeny and the terminal radionuclide used in +D and +E slope factors and dose coefficient development.

Progeny used for Derivation of +D and +E Slope Factors and Dose Coefficients

Principal Radionuclide (half-life in	Associated decay chain	Terminal Radionuclide	Half-life (years)

years)			
Cs-137+D (30.2)	Ba-137m	Ba-137	stable
Cs-137+E (30.2)	Ba-137m	Ba-137	stable
Pu-239+D (2.41E+04)	U-235m	U-235	7.04E+08
Pu-239+E (2.41E+04)	U-235m	U-235	7.04E+08
Ra-226+D (1.60E+03)	Rn-222, Po-218, Pb-214, At-218, Bi-214, Rn-218, Po-214, Tl-210	Pb-210	22
Ra-226+E (1.60E+03)	Rn-222, Po-218, Pb-214, At-218, Bi-214, Rn-218, Po-214, Tl-210	Pb-210	22
Ra-228+D (5.75E+00)	Ac-228	Th-228	2
Ra-228+E (5.75E+00)	Ac-228	Th-228	2
Rn-222+D (1.05E-02)	Po-218	Pb-214	5.10E-05
Rn-222+E (1.05E-02)	Po-218	Pb-214	5.10E-05
Sr-90+D (28.8)	Y-90	Zr-90	stable
Sr-90+E (28.8)	Y-90	Zr-90	stable
Th-232+D (1.41E+10)	Ra-228, Ac-228	Th-228	1.91E+00
Th-232+E (1.41E+10)	Ra-228, Ac-228, Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Po-212, Tl-208	Pb-208	stable
U-235+D (7.04E+08)	Th-231	Pa-231	3.3E+04
U-235+E (7.04E+08)	Th-231	Pa-231	3.3E+04
U-238+D (4.47E+09)	Th-234, Pa-234m, Pa-234	U-234	2.4E+05
U-238+E (4.47E+09)	Th-234, Pa-234m, Pa-234	U-234	2.4E+05

3. Using the PRG Table

The tables in the [PRG Download Area](#) provide generic concentrations in the absence of site-specific exposure assessments. Screening concentrations can be used to:

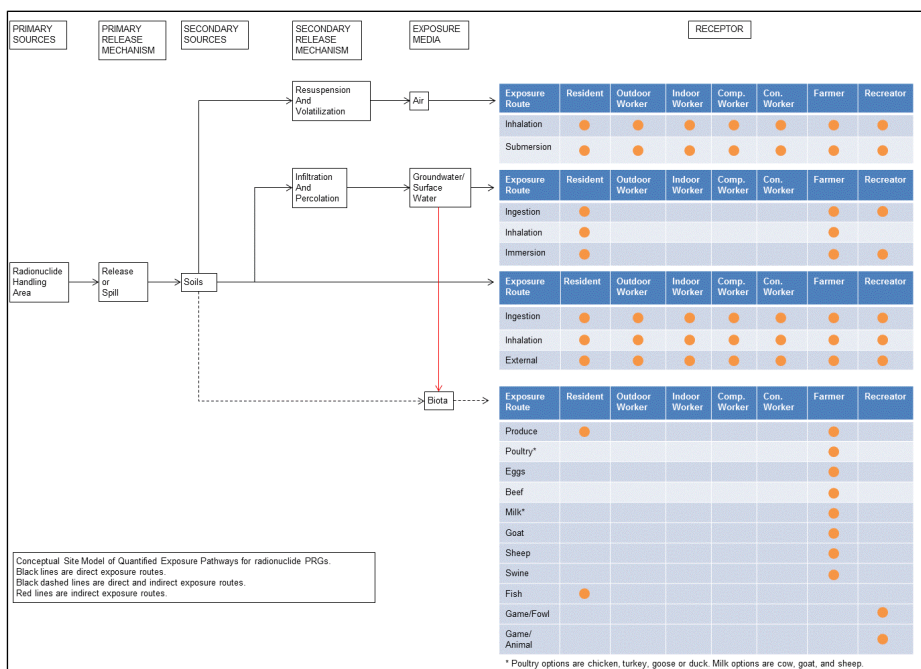
- Prioritize multiple sites within a facility or exposure units
- Prioritize risk-based detection limits for contaminants of potential concern (COPCs)
- Focus future risk assessment efforts
- When appropriate for the site, consider as risk-based cleanup levels

3.1 Developing a Conceptual Site Model

When using PRGs at a Superfund site, the exposure pathways of concern and site conditions should match those taken into account by the screening levels. (Note, however, that future uses may not match current uses. Future uses of a site should be logical conditions that might occur at the site in the future.) Thus, it is necessary to develop a conceptual site model (CSM) to identify likely contaminant source areas, exposure pathways, and potential receptors. This information can be used to determine the applicability of

screening levels at the site and the need for additional information. The final CSM diagram represents linkages among contaminant sources, release mechanisms, exposure pathways, and routes and receptors based on historical information. It summarizes the understanding of the contamination problem. A separate CSM for ecological receptors can be useful. [Part 2 and Attachment A](#) of the Soil Screening Guidance for Radionuclides: Users Guide (EPA 2000a) contains the steps for developing a CSM. A site-specific CSM may not include all of the land uses presented in this calculator.

The CSM below presents the land uses, media, and exposure routes quantified in this calculator along with hypothetical source and release mechanisms.



As a final check, the CSM should answer the following questions:

- Are there potential ecological concerns?
- Is there potential for land use other than those listed in the PRG calculator (i.e., resident and worker)?
- Are there other likely human exposure pathways that were not considered in development of the PRGs?
- Are there unusual site conditions (e.g., large areas of contamination, high fugitive dust levels, potential for indoor air contamination)?
- Are all current and potential future land uses presented?
- What media may become contaminated in the future?
- Is the selected PRG output option appropriate for the equilibrium of the site contaminants?

The PRGs may need to be adjusted to reflect the answers to these questions.

3.2 Background Radiation

Natural background radiation should be considered prior to applying PRGs as cleanup levels. Background and site-related levels of radiation will be addressed as they are for other contaminants at CERCLA sites; for further information, see EPA's guidance "[Role of Background in the CERCLA Cleanup Program](#)", April 2002, (EPA 2002a). It should be noted that certain ARARs specifically address how to factor background into cleanup levels. For example, some radiation ARAR levels are established as increments above background concentrations. In these circumstances, background should be addressed in the manner prescribed by the ARAR.

3.3 Potential Problems and Limitations

As with any risk-based tool, the potential exists for misapplication. In most cases, this results from not understanding the intended use of the PRGs. In order to prevent misuse of the PRGs, the following should be avoided:

- Applying PRG levels to a site without adequately developing a conceptual site model that identifies relevant exposure pathways and exposure scenarios;
- Use of PRG levels as cleanup levels without the consideration of other relevant criteria such as ARARs;
- Use of PRG levels as cleanup levels without verifying numbers with a health physicist/risk assessor;
- Use of outdated PRG levels tables that have been superseded by more recent publications;
- Not considering the effects from the presence of multiple isotopes; and
- Not considering the individual model limitations as described in section 4 (e.g., inhalation of tapwater only considers C-14 and H-3 as well as Rn-222, Rn-220, and Rn-219, including their short-lived progeny).

4. Land Use Descriptions, Equations, and Technical Documentation

The PRGs consider human exposure to contaminated air, soils, water, and biota. The equations and technical discussion are aimed at developing compliance levels for risk-based PRGs. The following text presents the land use equations and their exposure routes. [Table 1](#) (at the end of the User's Guide) presents the definitions of the variables and their default values. The default values and exposure models are consistent with the Regional Screening Levels for Chemical Contaminants at Superfund Sites ([RSL](#)) calculator where the same pathways are addressed (e.g., ingestion and inhalation) and are analogous where pathways are similar (e.g., dermal and external exposure). This calculator and the RSL both follow the recommendations in the [OSWER Directive](#) concerning use of exposure parameters from the [2011 Exposure Factors Handbook](#). Any alternative values or assumptions used in remedy evaluation or selection on a CERCLA site should be presented with supporting rationale in Administrative Records.

The PRG equations have evolved over time and are a combination of the following guidance documents:

- [Risk Assessment Guidance for Superfund: Volume I, Human Health Evaluation Manual \(Part B, Development of Risk-based Preliminary Remediation Goals\)](#) (RAGS Part B).
- U.S. EPA 2005. [Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities](#). Washington, DC. OSWER No. 5305W. EPA530-R-05-006.
- 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. EPA/540-R-00-007.
- 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.
- U.S. EPA 2002b. [Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites](#). OSWER 9355.4-24. December 2002.
- 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](#). Office of Emergency and Remedial Response. Office of Solid Waste. December 14.
- U.S. EPA 1996a. [Soil Screening Guidance: User's Guide](#). Office of Emergency and Remedial Response. Washington, DC. OSWER No. 9355.4-23
- U.S. EPA 1996b. [Soil Screening Guidance: Technical Background Document](#). Office of Emergency and Remedial Response. Washington, DC. OSWER No. 9355.4-17A
- 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](#).
- 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.

Users should note that if a route of exposure (e.g., ingesting fin fish from the pond in the farmer soil exposure scenario) is considered to be unreasonable at their site, both currently and in the future, they may eliminate the route in the site-specific option by entering zero for the intake rate of that route (e.g., replacing default fin fish intake rates in farmer soil scenario of 155.9 and 36.1 g/day with 0.0). Additionally, in site-specific mode, users can choose which produce and animal products to include in the assessment as well as select an appropriate climate zone and soil type that is reasonable for the given region.

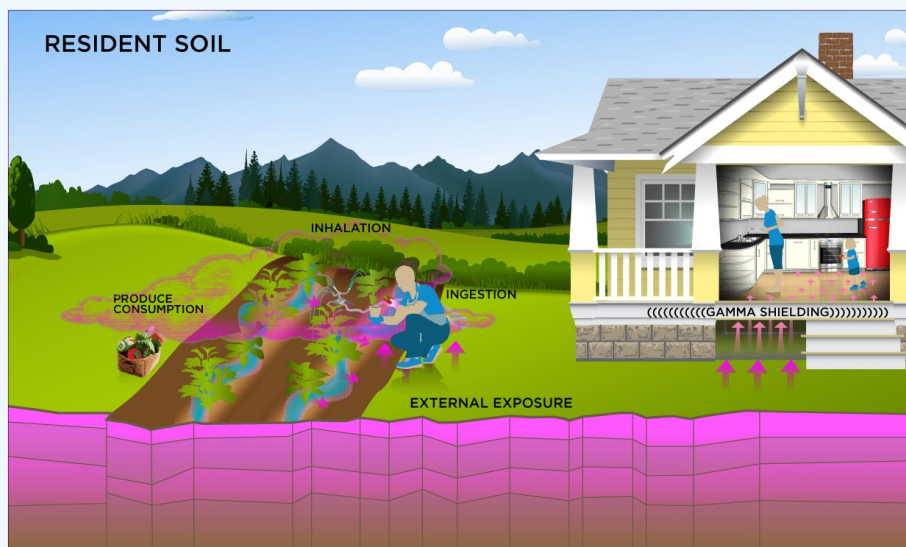
4.1 Resident

4.1.1 Resident Soil

This receptor spends most, if not all, of the day at home except for the hours spent at work. The activities for this receptor involve typical home chores (cooking, cleaning, and laundering) as well as gardening. The resident is assumed to be exposed to contaminants via the following pathways: incidental ingestion of soil, external radiation from contaminants in soil, and inhalation of fugitive dust and consumption of home grown produce (100% of fruit and vegetables). Adults and children exhibit different ingestion rates for soil and produce. For example, the child resident is assumed to ingest 200 mg per day while the adult ingests 100 mg per day. To take into account the different intake rate for children and adults, age-adjusted intake equations were developed to account for changes in intake as the receptor ages. In addition to the risk contribution from the media described in this section (soil, tapwater, biota, etc), building materials could be contributing to the overall risk. The [BPRG](#) can be used to calculate risk from contamination inside buildings. The [SPRG](#) can be used to calculate risk from contamination on outside building surfaces.

Note that the soil ingestion rates are intended to also represent ingestion of indoor dust. According to U.S. EPA 2011, "The source of the soil in these recommendations could be outdoor soil, indoor containerized soil used to support growth of indoor plants, or a combination of both outdoor soil and containerized indoor soil. The inhalation and subsequent swallowing of soil particles is accounted for in these recommended values, therefore, this pathway does not need to be considered separately." Further, according to U.S. EPA 1997, "Although the recommendations presented below are derived from studies which were mostly conducted in the summer, exposure during the winter months when the ground is frozen or snow covered should not be considered as zero. Exposure during these months, although lower than in the summer months, would not be zero because some portion of the house dust comes from outdoor soil."

Graphical Representation



PRG Equations

The resident soil land use equation, presented here, contains the following exposure routes:

- incidental ingestion of soil,

$$PRG_{res-soil-ing} (pCi/g) = \frac{TR}{SF_s \left(\frac{risk}{pCi} \right) \times IFS_{res-adj} (1,120,000 \text{ mg}) \times \left(\frac{g}{1000 \text{ mg}} \right)}$$

where:

$$IFS_{res-adj} (1,120,000 \text{ mg}) = \left(\left(EF_{res-c} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{res-c} (6 \text{ years}) \times IRS_{res-c} \left(\frac{200 \text{ mg}}{\text{day}} \right) \right) + \left(EF_{res-a} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{res-a} (20 \text{ years}) \times IRS_{res-a} \left(\frac{100 \text{ mg}}{\text{day}} \right) \right) \right)$$

- inhalation of particulates emitted from soil,

$$PRG_{res-soil-inh} (pCi/g) = \frac{TR}{SF_i \left(\frac{risk}{pCi} \right) \times IFA_{res-adj} \left(161,000 m^3 \right) \times \frac{1}{PEF \left(\frac{m^3}{kg} \right)} \times \left(\frac{1000 g}{kg} \right)}$$

where:

$$IFA_{res-adj} \left(161,000 m^3 \right) = \left(\left(EF_{res-c} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{res-c} \left(6 \text{ years} \right) \times ET_{res-c} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{res-c} \left(\frac{10 m^3}{\text{day}} \right) \right) + \left(EF_{res-a} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{res-a} \left(20 \text{ years} \right) \times ET_{res-a} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{res-a} \left(\frac{20 m^3}{\text{day}} \right) \right) \right)$$

• external exposure to ionizing radiation, and

$$PRG_{res-soil-ext} (pCi/g) = \frac{TR}{SF_{ext-sv} \left(\frac{risk/year}{pCi/g} \right) \times EF_{res} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{res} \left(26 \text{ years} \right) \times ACF_{ext-sv} \times \left[\left(ET_{res-o} \left(\frac{1,752 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{o-ext-sv} \right) + \left(ET_{res-i} \left(\frac{16,416 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{i-total} \right) \right]}$$

• consumption of fruits and vegetables - combined soil and biota . Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 9 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-grown produce.

$$PRG_{res-soil-produce-ing-tot} (pCi/g) = \frac{1}{\sum_{i=1}^n PRG_{res-soil-produce-ing} (pCi/g)_i}$$

where:

n = total number of produce items included

and:

$$PRG_{res-soil-produce-ing} (pCi/g) = \frac{PRG_{res-produce-ing} (pCi/g)}{\left(R_{upv} + R_{es} \right)}$$

where:

$$R_{upv} = Bv_{wet} \left(\frac{pCi / g-fresh \text{ plant}}{pCi / g-dry \text{ soil}} \right) ; R_{es} = MLF_{produce} \left(\frac{g-dry \text{ soil}}{g-fresh \text{ plant}} \right)$$

where:

$$PRG_{res-produce-ing} (pCi/g) = \frac{TR}{SF_f \left(\frac{risk}{pCi} \right) \times IF_{res-adj} (g) \times CF_{res-produce} (t)}$$

where:

$$IF_{res-adj} (g) = \left(\left(EF_{res-c} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{res-c} \left(6 \text{ years} \right) \times IR_{res-c} \left(\frac{g}{\text{day}} \right) \right) + \left(EF_{res-a} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{res-a} \left(20 \text{ years} \right) \times IR_{res-a} \left(\frac{g}{\text{day}} \right) \right) \right)$$

The consumption of produce exposure route drives the PRGs lower than all the other routes. It is recommended that produce-specific transfer factors (Bv_{wet}) be used when available for a site. Further, the default transfer factors (Bv_{wet}) from IAEA, used in these PRG calculations, are based on a composite of all soil groups. Transfer factors (Bv_{wet}) for sand, loam, clay, organic, coral sand, and other soil types that may be more suited to a particular site are also provided. The site-specific option of the calculator can be used to focus on ingestion of individual produce types. When "Site-Specific" is selected, if the user changes the "Select Isotope Info Type" to "User-provided", then a specific transfer factor may be changed.

• total

$$PRG_{res-soil-tot} (pCi/g) = \frac{1}{\frac{1}{PRG_{res-soil-ing}} + \frac{1}{PRG_{res-soil-inh}} + \frac{1}{PRG_{res-soil-ext}} + \frac{1}{PRG_{res-soil-produce-ing-tot}}}$$

A number of studies have shown that inadvertent ingestion of soil is common among children 6 years old and younger (Calabrese et al. 1989, Davis et al. 1990, Van Wijnen et al. 1990). Therefore, the dose method uses an age-adjusted soil ingestion factor that takes into account the difference in daily soil ingestion rates and exposure duration for children from 1 to 6 years old and others from 7 to 26 years old. This health-protective approach is chosen to take into account the higher daily rates

of soil ingestion in children as well as the longer duration of exposure that is anticipated for a long-term resident. For more on this method, see [RAGS Part B](#).

Age-adjusted intake factors are also used for inhalation of particulates emitted from soil and consumption of produce. These equations are also presented in the above equations.

Definitions of the input variables are in [Table 1](#).

CDI Equations

The resident soil land use equation, presented here, contains the following exposure routes:

- incidental ingestion of soil,

$$CDI_{\text{res-soil-ing}}(\text{pCi}) = C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times IFS_{\text{res-adj}}(1,120,000 \text{ mg}) \times \left(\frac{\text{g}}{1000 \text{ mg}} \right)$$

where:

$$IFS_{\text{res-adj}}(1,120,000 \text{ mg}) = \left(\left(EF_{\text{res-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{res-c}}(6 \text{ years}) \times IRS_{\text{res-c}} \left(\frac{200 \text{ mg}}{\text{day}} \right) \right) + \left(EF_{\text{res-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{res-a}}(20 \text{ years}) \times IRS_{\text{res-a}} \left(\frac{100 \text{ mg}}{\text{day}} \right) \right) \right)$$

- inhalation of particulates emitted from soil,

$$CDI_{\text{res-soil-inh}}(\text{pCi}) = C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times IFA_{\text{res-adj}}(161,000 \text{ m}^3) \times \frac{1}{PEF} \left(\frac{\text{m}^3}{\text{kg}} \right) \times \left(\frac{1000 \text{ g}}{\text{kg}} \right)$$

where:

$$IFA_{\text{res-adj}}(161,000 \text{ m}^3) = \left(\left(EF_{\text{res-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{res-c}}(6 \text{ years}) \times ET_{\text{res-c}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{\text{res-c}} \left(\frac{10 \text{ m}^3}{\text{day}} \right) \right) + \left(EF_{\text{res-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{res-a}}(20 \text{ years}) \times ET_{\text{res-a}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{\text{res-a}} \left(\frac{20 \text{ m}^3}{\text{day}} \right) \right) \right)$$

- external exposure to ionizing radiation, and

$$CDI_{\text{res-soil-ext}}(\text{pCi-year/g}) = \left(C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times EF_{\text{res}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{\text{res}}(26 \text{ years}) \times ACF_{\text{ext-sv}} \times \left[\left(ET_{\text{res-o}} \left(\frac{1,752 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{ext-sv}}(1.0) \right) + \left(ET_{\text{res-i}} \left(\frac{16,416 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{i-total}} \right) \right] \right)$$

- consumption of fruits and vegetables - combined soil and biota . Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 9 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-grown produce.

$$CDI_{\text{res-soil-produce-ing-tot}}(\text{pCi}) = \sum_{i=1}^n CDI_{\text{res-soil-produce-ing}}(\text{pCi})_i$$

where:

n = total number of produce items included

and:

$$CDI_{\text{res-soil-produce-ing}}(\text{pCi}) = C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times (R_{\text{upv}} + R_{\text{es}}) \times IF_{\text{res-adj}}(\text{g}) \times CF_{\text{res-produce}}(1)$$

where:

$$R_{\text{upv}} = Bv_{\text{wet}} \left(\frac{\text{pCi} / \text{g-fresh plant}}{\text{pCi} / \text{g-dry soil}} \right); R_{\text{es}} = MLF_{\text{produce}} \left(\frac{\text{g-dry soil}}{\text{g-fresh plant}} \right)$$

and:

$$IF_{\text{res-adj}}(\text{g}) = \left(\left(EF_{\text{res-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{res-c}}(6 \text{ years}) \times IR_{\text{res-c}} \left(\frac{\text{g}}{\text{day}} \right) \right) + \left(EF_{\text{res-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{res-a}}(20 \text{ years}) \times IR_{\text{res-a}} \left(\frac{\text{g}}{\text{day}} \right) \right) \right)$$

Definitions of the input variables are in [Table 1](#).

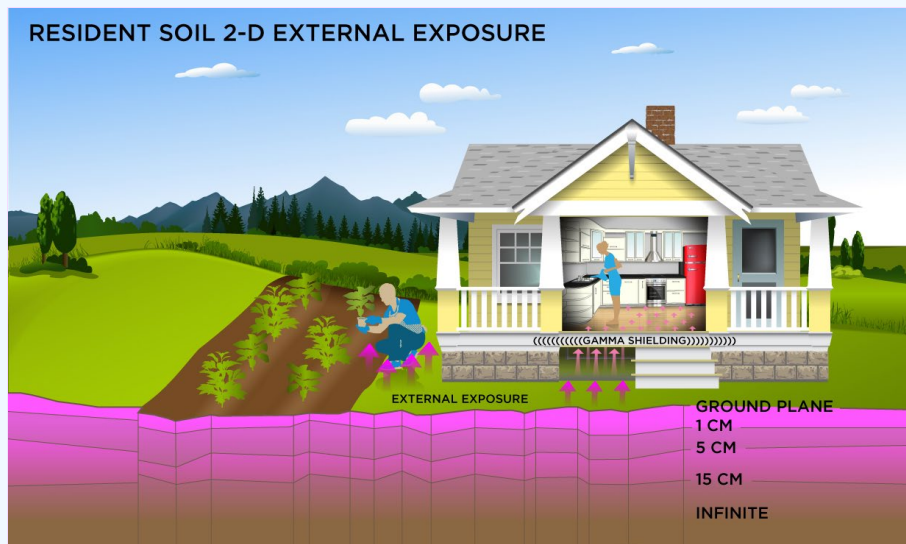
4.1.2 Resident Soil 2-D External Exposure

This receptor spends most, if not all, of the day at home except for the hours spent at work. The activities for this receptor involve typical home chores (cooking, cleaning, and laundering) as well as gardening.

This analysis is designed to look at external exposure from contamination of different area sizes.

Areas considered are 1 to 1,000,000 square meters. Isotope-specific area correction factor (ACF) were developed for this analysis.

Graphical Representation



PRG Equations

- Direct External Exposure to contamination at infinite depth

$$PRG_{res-soil-sv} (pCi/g) = \frac{TR}{SF_{ext-sv} \left(\frac{risk/year}{pCi/g} \right) \times EF_{res} \left(\frac{350 \text{ days}}{year} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{res} (26 \text{ years}) \times ACF_{ext-sv} \times \left[\left(ET_{res-o} \left(\frac{1.752 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{o-ext-sv} \right) + \left(ET_{res-i} \left(\frac{16.416 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{i-total} \right) \right]}$$

The resulting units for this recommended PRG are in pCi/g. The units are based on mass because the SF used is the soil volume for external exposure.

- Direct External Exposure to contamination 1 cm thick

$$PRG_{res-soil-1cm} (pCi/g) = \frac{TR}{SF_{ext-1cm} \left(\frac{risk/year}{pCi/g} \right) \times EF_{res} \left(\frac{350 \text{ days}}{year} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{res} (26 \text{ years}) \times ACF_{ext-1cm} \times \left[\left(ET_{res-o} \left(\frac{1.752 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{o-ext-1cm} \right) + \left(ET_{res-i} \left(\frac{16.416 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{i-total} \right) \right]}$$

The resulting units for this recommended PRG are in pCi/g. The units are based on mass because the SF used is the 1cm soil volume for external exposure.

- Direct External Exposure to contamination 5 cm thick

$$PRG_{res-soil-5cm} (pCi/g) = \frac{TR}{SF_{ext-5cm} \left(\frac{risk/year}{pCi/g} \right) \times EF_{res} \left(\frac{350 \text{ days}}{year} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{res} (26 \text{ years}) \times ACF_{ext-5cm} \times \left[\left(ET_{res-o} \left(\frac{1.752 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{o-ext-5cm} \right) + \left(ET_{res-i} \left(\frac{16.416 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{i-total} \right) \right]}$$

The resulting units for this recommended PRG are in pCi/g. The units are based on mass because the SF used is the 5cm soil volume for external exposure.

- Direct External Exposure to contamination 15 cm thick

$$PRG_{res-soil-15cm} (pCi/g) = \frac{TR}{SF_{ext-15cm} \left(\frac{risk/year}{pCi/g} \right) \times EF_{res} \left(\frac{350 \text{ days}}{year} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{res} (26 \text{ years}) \times ACF_{ext-15cm} \times \left[\left(ET_{res-o} \left(\frac{1.752 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{o-ext-15cm} \right) + \left(ET_{res-i} \left(\frac{16.416 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{i-total} \right) \right]}$$

The resulting units for this recommended PRG are in pCi/g. The units are based on mass because the SF used is the 15cm soil volume for external exposure.

- Direct External Exposure to surface contamination

$$PRG_{res-soil-gp} (pCi/cm^2) = \frac{TR}{SF_{ext-gp} \left(\frac{risk/year}{pCi/cm^2} \right) \times EF_{res} \left(\frac{350 \text{ days}}{year} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{res} (26 \text{ years}) \times ACF_{ext-gp} \times \left[\left(ET_{res-o} \left(\frac{1,752 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{o-ext-gp} \right) + \left(ET_{res-i} \left(\frac{16,416 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{i-total} \right) \right]}$$

The resulting units for this recommended PRG are in pCi/cm². The units are based on area because the SF used is the ground plane for external exposure.

Definitions of the input variables are in [Table 1](#).

CDI Equations

- Direct External Exposure to contamination at infinite depth

$$CDI_{res-soil-sv} (pCi-year/g) = \left(C_{soil} \left(\frac{pCi}{g} \right) \times ED_{res} (26 \text{ years}) \times EF_{res} \left(\frac{350 \text{ days}}{year} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{ext-sv} \times \left[\left(ET_{res-o} \left(\frac{1,752 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{ext-sv} (1.0) \right) + \left(ET_{res-i} \left(\frac{16,416 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{i-total} \right) \right] \right)$$

- Direct External Exposure to contamination 1 cm thick

$$CDI_{res-soil-1cm} (pCi-year/g) = \left(C_{soil} \left(\frac{pCi}{g} \right) \times ED_{res} (26 \text{ years}) \times EF_{res} \left(\frac{350 \text{ days}}{year} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{ext-1cm} \times \left[\left(ET_{res-o} \left(\frac{1,752 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{ext-1cm} (1.0) \right) + \left(ET_{res-i} \left(\frac{16,416 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{i-total} \right) \right] \right)$$

- Direct External Exposure to contamination 5 cm thick

$$CDI_{res-soil-5cm} (pCi-year/g) = \left(C_{soil} \left(\frac{pCi}{g} \right) \times ED_{res} (26 \text{ years}) \times EF_{res} \left(\frac{350 \text{ days}}{year} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{ext-5cm} \times \left[\left(ET_{res-o} \left(\frac{1,752 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{ext-5cm} (1.0) \right) + \left(ET_{res-i} \left(\frac{16,416 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{i-total} \right) \right] \right)$$

- Direct External Exposure to contamination 15 cm thick

$$CDI_{res-soil-15cm} (pCi-year/g) = \left(C_{soil} \left(\frac{pCi}{g} \right) \times ED_{res} (26 \text{ years}) \times EF_{res} \left(\frac{350 \text{ days}}{year} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{ext-15cm} \times \left[\left(ET_{res-o} \left(\frac{1,752 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{ext-15cm} (1.0) \right) + \left(ET_{res-i} \left(\frac{16,416 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{i-total} \right) \right] \right)$$

- Direct External Exposure to surface contamination

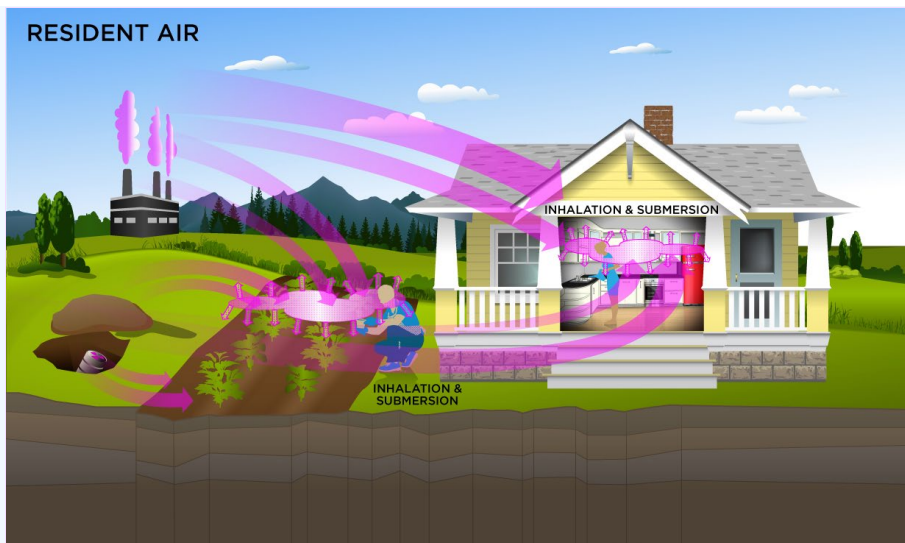
$$CDI_{res-soil-gp} (pCi-year/cm^2) = \left(C_{soil} \left(\frac{pCi}{cm^2} \right) \times ED_{res} (26 \text{ years}) \times EF_{res} \left(\frac{350 \text{ days}}{year} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{ext-gp} \times \left[\left(ET_{res-o} \left(\frac{1,752 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{ext-gp} (1.0) \right) + \left(ET_{res-i} \left(\frac{16,416 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{i-total} \right) \right] \right)$$

Definitions of the input variables are in [Table 1](#).

4.1.3 Resident Air

This receptor spends most, if not all, of the day at home except for the hours spent at work. The activities for this receptor involve typical home chores (cooking, cleaning, and laundering) as well as gardening. The resident is assumed to be exposed to contaminants via the following pathways: inhalation of ambient air and external radiation from contaminants in ambient air. To take into account the different inhalation rates for children and adults, age-adjusted intake equations were developed to account for changes in intake as the receptor ages.

Graphical Representation



PRG Equations

The resident ambient air land use equation, presented here, contains the following exposure routes:

- inhalation and

$$PRG_{res-air-inh} \left(pCi/m^3 \right) = \frac{TR}{SF_i \left(\frac{risk}{pCi} \right) \times IFA_{res-adj} \left(161,000 m^3 \right)}$$

where:

$$IFA_{res-adj} \left(161,000 m^3 \right) = \left(\left(EF_{res-c} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{res-c} (6 \text{ years}) \times ET_{res-c} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{res-c} \left(\frac{10 m^3}{\text{day}} \right) \right) + \left(EF_{res-a} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{res-a} (20 \text{ years}) \times ET_{res-a} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{res-a} \left(\frac{20 m^3}{\text{day}} \right) \right) \right)$$

- external exposure to ionizing radiation

$$PRG_{res-air-sub} \left(pCi/m^3 \right) = \frac{TR}{SF_{sub} \left(\frac{risk/year}{pCi/m^3} \right) \times EF_{res} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{res} (26 \text{ years}) \times ET_{res} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)}$$

- total

$$PRG_{res-air-tot} \left(pCi/m^3 \right) = \frac{1}{\frac{1}{PRG_{res-air-inh}} + \frac{1}{PRG_{res-air-sub}}}$$

In situations where the contaminant in the air is not being replenished (e.g., an accidental one-time air release from a factory), decay should be used. In situations where the contaminant in the air has a continual source (e.g., indoor radon from radium in the soil or an operating factory or landfill cap), the equations without decay should be used. The decay function, found in section 4.10.7, can be multiplied by the ambient air equations above to acquire ambient air PRGs with decay.

Definitions of the input variables are in [Table 1](#).

CDI Equations

The resident ambient air land use equation, presented here, contains the following exposure routes:

- inhalation and

$$CDI_{res-air-inh} (pCi) = C_{air} \left(\frac{pCi}{m^3} \right) \times IFA_{res-adj} \left(161,000 m^3 \right)$$

where:

$$IFA_{res-adj} \left(161,000 m^3 \right) = \left(\left(EF_{res-c} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{res-c} (6 \text{ years}) \times ET_{res-c} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{res-c} \left(\frac{10 m^3}{\text{day}} \right) \right) + \left(EF_{res-a} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{res-a} (20 \text{ years}) \times ET_{res-a} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{res-a} \left(\frac{20 m^3}{\text{day}} \right) \right) \right)$$

- external exposure to ionizing radiation

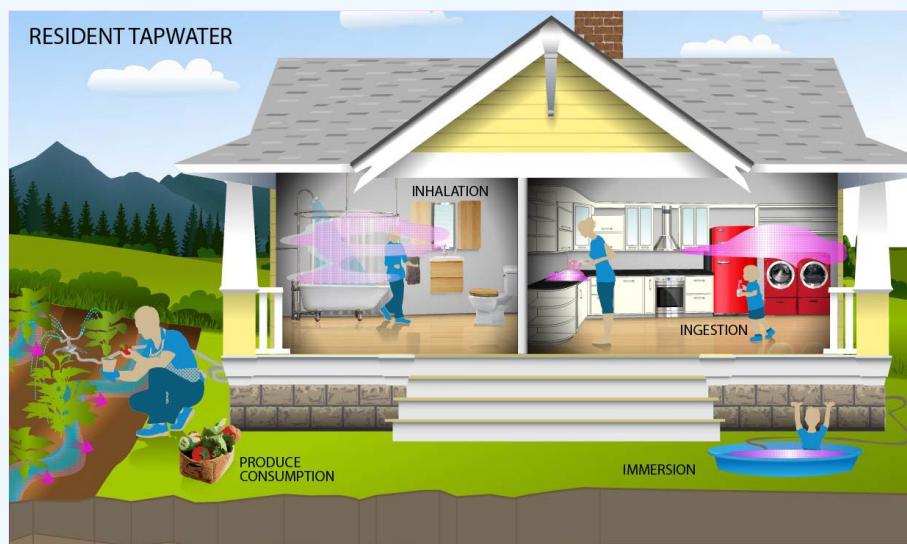
$$CDI_{\text{res-air-sub}} \left(\text{pCi}\cdot\text{year}/\text{m}^3 \right) = C_{\text{air}} \left(\frac{\text{pCi}}{\text{m}^3} \right) \times EF_{\text{res}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{\text{res}} (26 \text{ years}) \times ET_{\text{res}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)$$

Definitions of the input variables are in [Table 1](#).

4.1.4 Resident Tapwater

This receptor is exposed to radionuclides in water that are delivered into a residence. The source of the contamination, such as groundwater vs. surface water, is not relevant to the calculations. Ingestion of drinking water is an appropriate pathway for all radionuclides. Activities such as showering, laundering, and dish washing also contribute to the inhalation exposure route. The inhalation exposure route is only calculated for C-14, H-3, Rn-219, Rn-220, Rn-222, and the radon short-lived progeny that remain airborne for a time. If a user selects an isotope that decays into one of the three radons (i.e., Ac-227, Pu-240, U-238, etc.), the inhalation route will be calculated for the radon and its short-lived progeny. The resident default air exchange rate is set at 0.18 per hour. When the calculator is operated in site-specific mode, the user can adjust the air exchange rate, which alters the levels of radon progeny in the air available for inhalation. Section 4.10.8 presents the details of the radon progeny included in the tapwater inhalation route. External exposure to immersion in tapwater and exposure to produce irrigated with contaminated tapwater are also considered.

Graphical Representation



PRG Equations

The tapwater land use equation, presented here, contains the following exposure routes:

- ingestion of tapwater,

$$PRG_{\text{res-water-ing}} \left(\text{pCi}/\text{L} \right) = \frac{TR}{SF_w \left(\frac{\text{risk}}{\text{pCi}} \right) \times IFW_{\text{res-adj}} (19,138 \text{ L})}$$

where:

$$IFW_{\text{res-adj}} (19,138 \text{ L}) = \left(\left(EF_{\text{res-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{res-c}} (6 \text{ years}) \times IRW_{\text{res-c}} \left(\frac{0.78 \text{ L}}{\text{day}} \right) \right) + \left(EF_{\text{res-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{res-a}} (20 \text{ years}) \times IRW_{\text{res-a}} \left(\frac{2.5 \text{ L}}{\text{day}} \right) \right) \right)$$

- inhalation, (The inhalation exposure route is only calculated for C-14 and H-3 as well as Rn-222, Rn-220, and Rn-219, including their short-lived progeny. Also, volatilization in the equation comes from household uses of water (e.g., showering, laundering, dish washing)).

$$PRG_{res-water-inh} (pCi/L) = \frac{TR}{SF_i \left(\frac{risk}{pCi} \right) \times IFA_{res-adj} \left(161,100 \text{ m}^3 \right) \times K \left(\frac{0.5 \text{ L}}{\text{m}^3} \right)}$$

where:

$$IFA_{res-adj} \left(161,100 \text{ m}^3 \right) = \left(\left(EF_{res-c} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{res-c} (6 \text{ years}) \times ET_{res-c} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{res-c} \left(\frac{10 \text{ m}^3}{\text{day}} \right) \right) + \left(EF_{res-a} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{res-a} (20 \text{ years}) \times ET_{res-a} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{res-a} \left(\frac{20 \text{ m}^3}{\text{day}} \right) \right) \right)$$

- immersion, and

$$PRG_{res-water-imm} (pCi/L) = \frac{TR}{SF_{imm} \left(\frac{risk/year}{pCi/L} \right) \times \left(\frac{1 \text{ year}}{8760 \text{ hours}} \right) \times DFA_{res-adj} (6104 \text{ hours})}$$

where:

$$DFA_{res-adj} (6104 \text{ hours}) = \left(\left(EF_{res-c} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{res-c} (6 \text{ years}) \times EV_{res-c} \left(\frac{1 \text{ event}}{\text{day}} \right) \times ET_{event-res-c} \left(\frac{0.54 \text{ hours}}{\text{event}} \right) \right) + \left(EF_{res-a} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{res-a} (20 \text{ years}) \times EV_{res-a} \left(\frac{1 \text{ event}}{\text{day}} \right) \times ET_{event-res-a} \left(\frac{0.71 \text{ hours}}{\text{event}} \right) \right) \right)$$

- consumption of fruits and vegetables - combined water and biota, Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 9 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-grown produce.

$$PRG_{res-water-produce-ing-tot} (pCi/L) = \frac{1}{\sum_{i=1}^n PRG_{res-water-produce-ing} (pCi/L)_i}$$

where:

n = total number of produce items included

and:

$$PRG_{res-water-produce-ing} (pCi/L) = \frac{PRG_{res-produce-ing} (pCi/g)}{\left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \times \left(Irr_{rup} \left(\frac{L}{kg} \right) + Irr_{res} \left(\frac{L}{kg} \right) + Irr_{dep} \left(\frac{L}{kg} \right) \right)}$$

where:

$$Irr_{res} \left(\frac{L}{kg} \right) = \frac{I_r \left(\frac{L}{m^2 \cdot \text{day}} \right) \times F \times MLF_{produce} \times \left[1 - \exp \left(- \left(\frac{\lambda_B}{\text{day}} \right) \times t_b (\text{days}) \right) \right]}{P \left(\frac{kg}{m^2} \right) \times \left(\frac{\lambda_B}{\text{day}} \right)}$$

$$Irr_{rup} \left(\frac{L}{kg} \right) = \frac{I_r \left(\frac{L}{m^2 \cdot \text{day}} \right) \times F \times B_{v \text{ wet}} \times \left[1 - \exp \left(- \left(\frac{\lambda_B}{\text{day}} \right) \times t_b (\text{days}) \right) \right]}{P \left(\frac{kg}{m^2} \right) \times \left(\frac{\lambda_B}{\text{day}} \right)}$$

and:

$$Irr_{dep} \left(\frac{L}{kg} \right) = \frac{I_r \left(\frac{L}{m^2 \cdot \text{day}} \right) \times F \times I_f \times T \times \left[1 - \exp \left(- \left(\frac{\lambda_E}{\text{day}} \right) \times t_v (\text{days}) \right) \right]}{Y_v \left(\frac{kg}{m^2} \right) \times \left(\frac{\lambda_E}{\text{day}} \right)}$$

where:

$$PRG_{res-produce-ing} (pCi/g) = \frac{TR}{SF_f \left(\frac{risk}{pCi} \right) \times IF_{res-adj} (g) \times CF_{res-produce} (l)}$$

where:

$$IF_{res-adj} (g) = \left(\left(EF_{res-c} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{res-c} (6 \text{ years}) \times IR_{res-c} \left(\frac{g}{\text{day}} \right) \right) + \left(EF_{res-a} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{res-a} (20 \text{ years}) \times IR_{res-a} \left(\frac{g}{\text{day}} \right) \right) \right)$$

- total

$$PRG_{res-water-tot} (pCi/L) = \frac{1}{\frac{1}{PRG_{res-water-ing}} + \frac{1}{PRG_{res-water-inh}} + \frac{1}{PRG_{res-water-imm}} + \frac{1}{PRG_{res-water-produce-ing-tot}}}$$

Definitions of the input variables are in [Table 1](#).

CDI Equations

The tapwater land use equation, presented here, contains the following exposure routes:

- ingestion of tapwater,

$$CDI_{\text{res-water-ing}} (\text{pCi}) = C_{\text{g-water}} \left(\frac{\text{pCi}}{\text{L}} \right) \times IFW_{\text{res-adj}} (19,138 \text{ L})$$

where:

$$IFW_{\text{res-adj}} (19,138 \text{ L}) = \left(\left(EF_{\text{res-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{res-c}} (6 \text{ years}) \times IRW_{\text{res-c}} \left(\frac{0.78 \text{ L}}{\text{day}} \right) \right) + \left(EF_{\text{res-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{res-a}} (20 \text{ years}) \times IRW_{\text{res-a}} \left(\frac{2.5 \text{ L}}{\text{day}} \right) \right) \right)$$

- inhalation, (The inhalation exposure route is only calculated for C-14 and H-3 as well as Rn-222, Rn-220, and Rn-219, including their short-lived progeny. Also, volatilization in the equation comes from household uses of water (e.g., showering, laundering, dish washing)).

$$CDI_{\text{res-water-inh}} (\text{pCi}) = C_{\text{g-water}} \left(\frac{\text{pCi}}{\text{L}} \right) \times IFA_{\text{res-adj}} (161,100 \text{ m}^3) \times k \left(\frac{0.5 \text{ L}}{\text{m}^3} \right)$$

where:

$$IFA_{\text{res-adj}} (161,100 \text{ m}^3) = \left(\left(EF_{\text{res-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{res-c}} (6 \text{ years}) \times ET_{\text{res-c}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{\text{res-c}} \left(\frac{10 \text{ m}^3}{\text{day}} \right) \right) + \left(EF_{\text{res-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{res-a}} (20 \text{ years}) \times ET_{\text{res-a}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{\text{res-a}} \left(\frac{20 \text{ m}^3}{\text{day}} \right) \right) \right)$$

- immersion, and

$$CDI_{\text{res-water-imm}} (\text{pCi-year/L}) = C_{\text{g-water}} \left(\frac{\text{pCi}}{\text{L}} \right) \times \left(\frac{1 \text{ year}}{8760 \text{ hours}} \right) \times DFA_{\text{res-adj}} (6104 \text{ hours})$$

where:

$$DFA_{\text{res-adj}} (6104 \text{ hours}) = \left(\left(EF_{\text{res-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{res-c}} (6 \text{ years}) \times EV_{\text{res-c}} \left(\frac{1 \text{ event}}{\text{day}} \right) \times ET_{\text{event-res-c}} \left(\frac{0.54 \text{ hours}}{\text{event}} \right) \right) + \left(EF_{\text{res-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{res-a}} (20 \text{ years}) \times EV_{\text{res-a}} \left(\frac{1 \text{ event}}{\text{day}} \right) \times ET_{\text{event-res-a}} \left(\frac{0.71 \text{ hours}}{\text{event}} \right) \right) \right)$$

- consumption of fruits and vegetables - combined water and biota, Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 9 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-grown produce.

$$CDI_{\text{res-water-produce-tot}}(pCi) = \sum_{i=1}^n CDI_{\text{res-water-produce-ing}}(pCi)_i$$

where:

n = total number of produce items included

and:

$$CDI_{\text{res-water-produce}}(pCi) = \left(C_{\text{g-water}} \left(\frac{pCi}{L} \right) \times IF_{\text{res-adj}}(g) \times CF_{\text{res-produce}}(1) \times \left[\left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \times \left(Irr_{\text{rup}} \left(\frac{L}{kg} \right) + Irr_{\text{res}} \left(\frac{L}{kg} \right) + Irr_{\text{dep}} \left(\frac{L}{kg} \right) \right] \right)$$

where:

$$Irr_{\text{res}} \left(\frac{L}{kg} \right) = \frac{Ir \left(\frac{L}{m^2 \cdot \text{day}} \right) \times F \times MLF_{\text{produce}} \times \left[1 - \exp \left(- \left(\frac{\lambda_B}{\text{day}} \right) \times t_b \text{ (days)} \right) \right]}{P \left(\frac{kg}{m^2} \right) \times \left(\frac{\lambda_B}{\text{day}} \right)};$$

$$Irr_{\text{rup}} \left(\frac{L}{kg} \right) = \frac{Ir \left(\frac{L}{m^2 \cdot \text{day}} \right) \times F \times B_{\text{v wet}} \times \left[1 - \exp \left(- \left(\frac{\lambda_B}{\text{day}} \right) \times t_b \text{ (days)} \right) \right]}{P \left(\frac{kg}{m^2} \right) \times \left(\frac{\lambda_B}{\text{day}} \right)};$$

and:

$$Irr_{\text{dep}} \left(\frac{L}{kg} \right) = \frac{Ir \left(\frac{L}{m^2 \cdot \text{day}} \right) \times F \times I_f \times T \times \left[1 - \exp \left(- \left(\frac{\lambda_E}{\text{day}} \right) \times t_v \text{ (days)} \right) \right]}{Y_v \left(\frac{kg}{m^2} \right) \times \left(\frac{\lambda_E}{\text{day}} \right)}$$

and:

$$IF_{\text{res-adj}}(g) = \left(\left(EF_{\text{res-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{res-c}}(6 \text{ years}) \times IR_{\text{res-c}} \left(\frac{g}{\text{day}} \right) \right) + \left(EF_{\text{res-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{res-a}}(20 \text{ years}) \times IR_{\text{res-a}} \left(\frac{g}{\text{day}} \right) \right) \right)$$

Definitions of the input variables are in [Table 1](#).

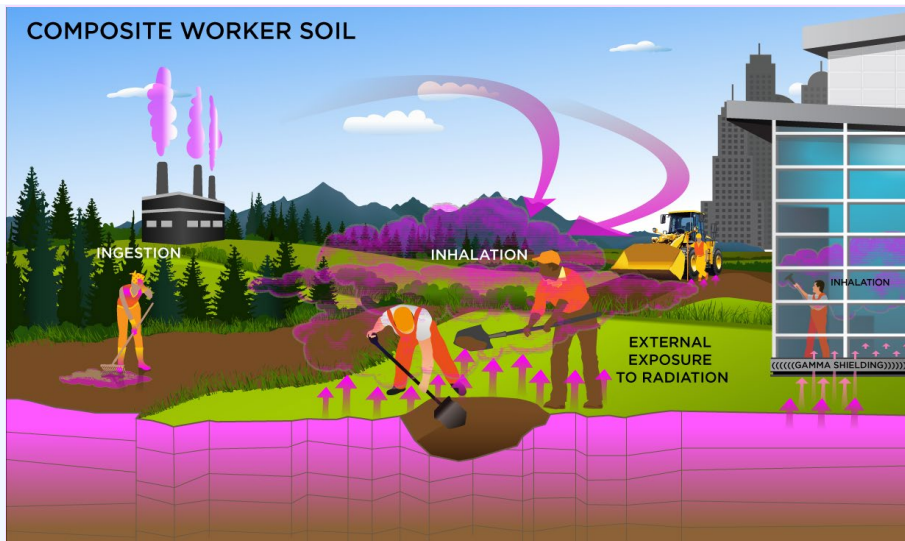
4.2 Composite Worker

4.2.1 Composite Worker Soil

This long-term receptor, exposed during the work day, is a full time employee working on-site who spends most of the workday conducting maintenance activities outdoors. The activities for this receptor (e.g., moderate digging, landscaping) typically involve on-site exposures to surface soils. The composite worker is expected to have an elevated soil ingestion rate (100 mg per day) and is assumed to be exposed to contaminants via the following pathways: incidental ingestion of soil, external radiation from contaminants in soil, and inhalation of fugitive dust. The composite worker combines the most protective exposure assumptions of the outdoor and indoor workers. The only difference between the outdoor worker and the composite worker is that the composite worker uses the more protective exposure frequency of 250 days/year from the indoor worker scenario.

This land use is used to develop industrial default screening levels that are presented in the [Download Area](#).

Graphical Representation



PRG Equations

The composite worker soil land use equations, presented here, contain the following exposure routes:

- incidental ingestion of soil,

$$PRG_{w-soil-ing} (pCi/g) = \frac{TR}{SF_{sa} \left(\frac{risk}{pCi} \right) \times EF_w \left(\frac{250 \text{ days}}{year} \right) \times ED_w (25 \text{ years}) \times IRS_w \left(\frac{100 \text{ mg}}{day} \right) \times \left(\frac{g}{1000 \text{ mg}} \right)}$$

- inhalation of particulates emitted from soil,

$$PRG_{w-soil-inh} (pCi/g) = \frac{TR}{SF_i \left(\frac{risk}{pCi} \right) \times EF_w \left(\frac{250 \text{ day}}{year} \right) \times ED_w (25 \text{ years}) \times \left(\frac{1000 \text{ g}}{kg} \right) \times ET_w \left(\frac{8 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_w \left(\frac{60 \text{ m}^3}{day} \right) \times \frac{1}{PEF \left(\frac{\text{m}^3}{kg} \right)}}$$

- external exposure to ionizing radiation, and

$$PRG_{w-soil-ext} (pCi/g) = \frac{TR}{SF_{ext-sv} \left(\frac{risk/year}{pCi/g} \right) \times EF_w \left(\frac{250 \text{ day}}{year} \right) \times \left(\frac{1 \text{ year}}{365 \text{ day}} \right) \times ACF_{ext-sv} \times ED_w (25 \text{ years}) \times ET_w \left(\frac{8 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{o-ext-sv}}$$

- total

$$PRG_{w-soil-tot} (pCi/g) = \frac{1}{\frac{1}{PRG_{w-soil-ing}} + \frac{1}{PRG_{w-soil-inh}} + \frac{1}{PRG_{w-soil-ext}}}$$

Definitions of the input variables are in [Table 1](#).

CDI Equations

The composite worker soil land use equations, presented here, contain the following exposure routes:

- incidental ingestion of soil,

$$CDI_{w-soil-ing} (pCi) = C_{soil} \left(\frac{pCi}{g} \right) \times EF_w \left(\frac{250 \text{ days}}{year} \right) \times ED_w (25 \text{ years}) \times IRS_w \left(\frac{100 \text{ mg}}{day} \right) \times \left(\frac{g}{1000 \text{ mg}} \right)$$

- inhalation of particulates emitted from soil, and

$$CDI_{w-soil-inh} (pCi) = C_{soil} \left(\frac{pCi}{g} \right) \times EF_w \left(\frac{250 \text{ days}}{year} \right) \times ED_w (25 \text{ years}) \times ET_w \left(\frac{8 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_w \left(\frac{60 \text{ m}^3}{day} \right) \times \frac{1}{PEF \left(\frac{\text{m}^3}{kg} \right)} \times \left(\frac{1000 \text{ g}}{kg} \right)$$

- external exposure to ionizing radiation

$$CDI_{w\text{-soil-ext}} (\text{pCi-year/g}) = \left(C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_w (25 \text{ years}) \times \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{ext-sv}} (1.0) \times ACF_{\text{ext-sv}} \right)$$

Definitions of the input variables are in [Table 1](#).

4.2.2 Composite Worker Soil 2-D External Exposure

This long-term receptor, exposed during the work day, is a full time employee working on-site who spends most of the workday conducting maintenance activities outdoors. The activities for this receptor (e.g., moderate digging, landscaping) typically involve on-site exposures to surface soils.

This analysis is designed to look at external exposure from contamination of different area sizes. Areas considered are 1 to 1,000,000 square meters. Isotope-specific area correction factor (ACF) were developed for this analysis.

Graphical Representation



PRG Equations

- Direct External Exposure to contamination at infinite depth

$$PRG_{w\text{-soil-sv}} (\text{pCi/g}) = \frac{TR}{SF_{\text{ext-sv}} \left(\frac{\text{risk/year}}{\text{pCi/g}} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{\text{ext-sv}} \times ED_w (25 \text{ year}) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{o-ext-sv}}}$$

The resulting units for this recommended PRG are in pCi/g. The units are based on mass because the SF used is the soil volume for external exposure.

- Direct External Exposure to contamination 1 cm thick

$$PRG_{w\text{-soil-1cm}} (\text{pCi/g}) = \frac{TR}{SF_{\text{ext-1cm}} \left(\frac{\text{risk/year}}{\text{pCi/g}} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{\text{ext-1cm}} \times ED_w (25 \text{ years}) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{o-ext-1cm}}$$

The resulting units for this recommended PRG are in pCi/g. The units are based on mass because the SF used is the 1cm soil volume for external exposure.

- Direct External Exposure to contamination 5 cm thick

$$PRG_{w\text{-soil-5cm}} (\text{pCi/g}) = \frac{TR}{SF_{\text{ext-5cm}} \left(\frac{\text{risk/year}}{\text{pCi/g}} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{\text{ext-5cm}} \times ED_w (25 \text{ year}) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{o-ext-5cm}}$$

The resulting units for this recommended PRG are in pCi/g. The units are based on mass because the SF used is the 5cm soil volume for external exposure.

- Direct External Exposure to contamination 15 cm thick

$$PRG_{w\text{-soil-15cm}} (\text{pCi/g}) = \frac{TR}{SF_{\text{ext-15cm}} \left(\frac{\text{risk/year}}{\text{pCi/g}} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{\text{ext-15cm}} \times ED_w (25 \text{ year}) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{o-ext-15cm}}}$$

The resulting units for this recommended PRG are in pCi/g. The units are based on mass because the SF used is the 15cm soil volume for external exposure.

- Direct External Exposure to surface contamination

$$PRG_{w\text{-soil-gp}} (\text{pCi/cm}^2) = \frac{TR}{SF_{\text{ext-gp}} \left(\frac{\text{risk/year}}{\text{pCi/cm}^2} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{\text{ext-gp}} \times ED_w (25 \text{ year}) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{o-ext-gp}}}$$

The resulting units for this recommended PRG are in pCi/cm². The units are based on area because the SF used is the ground plane for external exposure.

Definitions of the input variables are in [Table 1](#).

CDI Equations

- Direct External Exposure to contamination at infinite depth

$$CDI_{w\text{-soil-sv}} (\text{pCi-year/g}) = \left(C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_w (25 \text{ years}) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{ext-sv}} (1.0) \times ACF_{\text{ext-sv}} \right)$$

- Direct External Exposure to contamination 1 cm thick

$$CDI_{w\text{-soil-1cm}} (\text{pCi-year/g}) = \left(C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_w (25 \text{ years}) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{ext-1cm}} (1.0) \times ACF_{\text{ext-1cm}} \right)$$

- Direct External Exposure to contamination 5 cm thick

$$CDI_{w\text{-soil-5cm}} (\text{pCi-year/g}) = \left(C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_w (25 \text{ years}) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{ext-5cm}} (1.0) \times ACF_{\text{ext-5cm}} \right)$$

- Direct External Exposure to contamination 15 cm thick

$$CDI_{w\text{-soil-15cm}} (\text{pCi-year/g}) = \left(C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_w (25 \text{ years}) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{ext-15cm}} (1.0) \times ACF_{\text{ext-15cm}} \right)$$

- Direct External Exposure to surface contamination

$$CDI_{w\text{-soil-gp}} (\text{pCi-year/cm}^2) = \left(C_{\text{soil}} \left(\frac{\text{pCi}}{\text{cm}^2} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_w (25 \text{ years}) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{ext-gp}} (1.0) \times ACF_{\text{ext-gp}} \right)$$

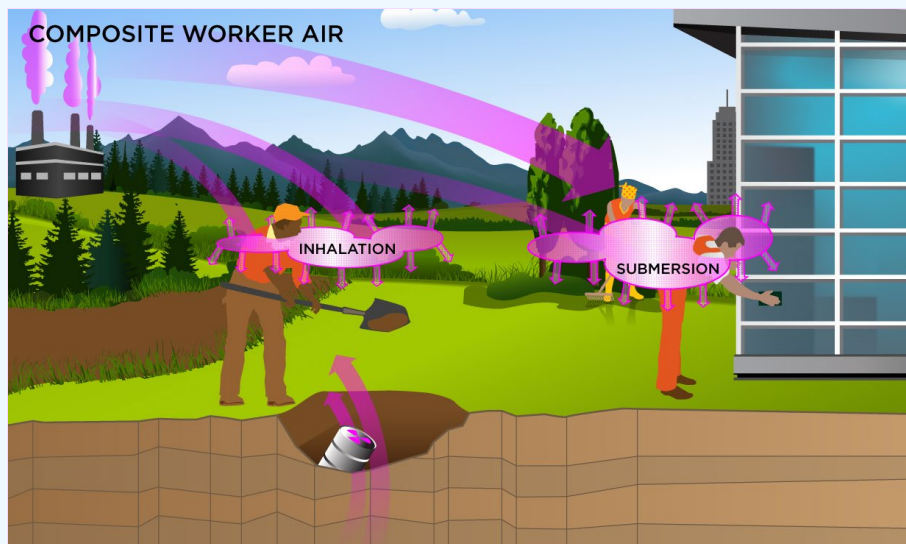
Definitions of the input variables are in [Table 1](#).

4.2.3 Composite Worker Air

This long-term receptor, exposed during the work day, is a full time employee working on-site who spends most of the workday conducting maintenance activities outdoors. The activities for this receptor (e.g., moderate digging, landscaping) typically involve on-site exposures to surface soils. The composite worker is assumed to be exposed to contaminants via the following pathways:

inhalation of ambient air and external radiation from contaminants in ambient air. The composite worker combines the most protective exposure assumptions of the outdoor and indoor workers. The only difference between the outdoor worker and the composite worker is that the composite worker uses the more protective exposure frequency of 250 days/year from the indoor worker scenario.

Graphical Representation



PRG Equations

The composite worker ambient air land use equation, presented here, contains the following exposure routes:

- inhalation and

$$\text{PRG}_{\text{w-air-inh}} \left(\text{pCi/m}^3 \right) = \frac{\text{TR}}{\text{SF}_i \left(\frac{\text{risk}}{\text{pCi}} \right) \times \text{EF}_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \text{ED}_w (25 \text{ years}) \times \text{ET}_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{IRA}_w \left(\frac{60 \text{ m}^3}{\text{day}} \right)}$$

- external exposure to ionizing radiation

$$\text{PRG}_{\text{w-air-sub}} \left(\text{pCi/m}^3 \right) = \frac{\text{TR}}{\text{SF}_{\text{sub}} \left(\frac{\text{risk/year}}{\text{pCi/m}^3} \right) \times \text{EF}_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times \text{ED}_w (25 \text{ years}) \times \text{ET}_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{GSF}_a (1.0)}$$

- total

$$\text{PRG}_{\text{w-air-tot}} \left(\text{pCi/m}^3 \right) = \frac{1}{\frac{1}{\text{PRG}_{\text{w-air-inh}}} + \frac{1}{\text{PRG}_{\text{w-air-sub}}}}$$

In situations where the contaminant in the air is not being replenished (e.g., an accidental one-time air release from a factory), decay should be used. In situations where the contaminant in the air has a continual source (e.g., indoor radon from radium in the soil or an operating factory or landfill cap), the equations without decay should be used. The decay function, found in section 4.10.7, can be multiplied by the ambient air equations above to acquire ambient air PRGs with decay.

Definitions of the input variables are in [Table 1](#).

CDI Equations

The composite worker ambient air land use equation, presented here, contains the following exposure routes:

- inhalation and

$$\text{CDI}_{\text{w-air-inh}} (\text{pCi}) = C_{\text{air}} \left(\frac{\text{pCi}}{\text{m}^3} \right) \times \text{EF}_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \text{ED}_w (25 \text{ years}) \times \text{ET}_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{IRA}_w \left(\frac{60 \text{ m}^3}{\text{day}} \right)$$

- external exposure to ionizing radiation

$$CDI_{w-air-sub} \left(\text{pCi-year}/\text{m}^3 \right) = C_{air} \left(\frac{\text{pCi}}{\text{m}^3} \right) \times EF_w \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ day}} \right) \times ED_w (25 \text{ years}) \times ET_w \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)$$

Definitions of the input variables are in [Table 1](#).

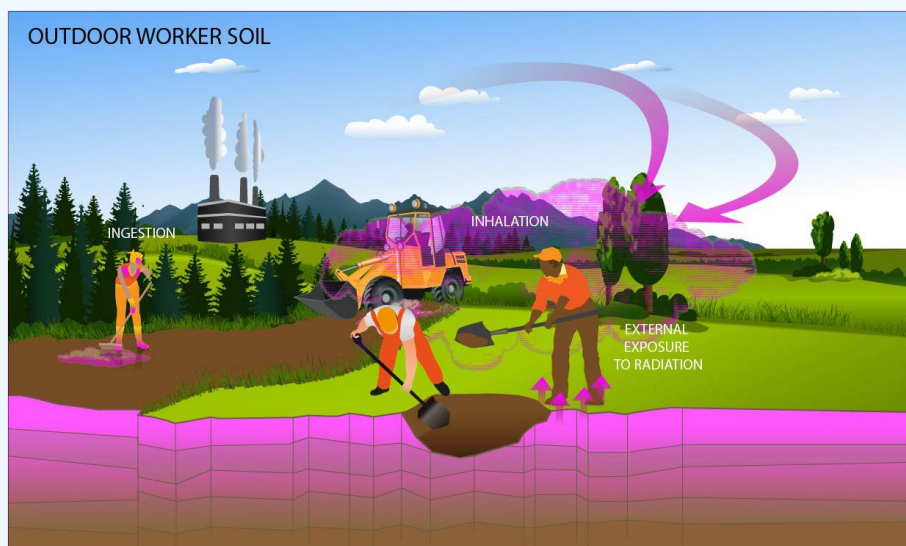
4.3 Outdoor Worker

4.3.1 Outdoor Worker Soil

This long-term receptor, exposed during the work day, is a full time employee working on-site who spends most of the workday conducting maintenance activities outdoors. The activities for this receptor (e.g., moderate digging, landscaping) typically involve on-site exposures to surface soils. The outdoor worker is expected to have an elevated soil ingestion rate (100 mg per day) and is assumed to be exposed to contaminants via the following pathways: incidental ingestion of soil, external radiation from contaminants in soil, and inhalation of fugitive dust. The outdoor worker receives more exposure than the indoor worker under commercial/industrial conditions.

The outdoor worker soil land use is not provided in the Download Area, but PRGs can be created by using the Calculator to modify the exposure parameters for the composite worker to match the equations that follow.

Graphical Representation



PRG Equations

The outdoor worker soil land use equations, presented here, contain the following exposure routes:

- incidental ingestion of soil,

$$PRG_{ow-soil-ing} \left(\text{pCi/g} \right) = \frac{TR}{SF_{sa} \left(\frac{\text{risk}}{\text{pCi}} \right) \times EF_{ow} \left(\frac{225 \text{ days}}{\text{year}} \right) \times ED_{ow} (25 \text{ years}) \times IRS_{ow} \left(\frac{100 \text{ mg}}{\text{day}} \right) \times \left(\frac{\text{g}}{1000 \text{ mg}} \right)}$$

- inhalation of particulates emitted from soil, and

$$PRG_{ow-soil-inh} \left(\text{pCi/g} \right) = \frac{TR}{SF_i \left(\frac{\text{risk}}{\text{pCi}} \right) \times EF_{ow} \left(\frac{225 \text{ days}}{\text{year}} \right) \times ED_{ow} (25 \text{ years}) \times \left(\frac{1000 \text{ g}}{\text{kg}} \right) \times ET_{ow} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{ow} \left(\frac{60 \text{ m}^3}{\text{day}} \right) \times \frac{1}{PEF \left(\frac{\text{m}^3}{\text{kg}} \right)}}$$

- external exposure to ionizing radiation

$$PRG_{ow-soil-ext} \left(\text{pCi/g} \right) = \frac{TR}{SF_{ext-sv} \left(\frac{\text{risk/year}}{\text{pCi/g}} \right) \times EF_{ow} \left(\frac{225 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{ext-sv} \times ED_{ow} (25 \text{ years}) \times ET_{ow} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{o-ext-sv}}$$

- total

$$PRG_{ow-soil-tot} (pCi/g) = \frac{1}{\frac{1}{PRG_{ow-soil-ing}} + \frac{1}{PRG_{ow-soil-inh}} + \frac{1}{PRG_{ow-soil-ext}}}$$

Definitions of the input variables are in [Table 1](#).

CDI Equations

The outdoor worker soil land use equations, presented here, contain the following exposure routes:

- incidental ingestion of soil,

$$CDI_{ow-soil-ing} (pCi) = C_{soil} \left(\frac{pCi}{g} \right) \times EF_{ow} \left(\frac{225 \text{ days}}{\text{year}} \right) \times ED_{ow} (25 \text{ years}) \times IRS_{ow} \left(\frac{100 \text{ mg}}{\text{day}} \right) \times \left(\frac{g}{1000 \text{ mg}} \right)$$

- inhalation of particulates emitted from soil, and

$$CDI_{ow-soil-inh} (pCi) = C_{soil} \left(\frac{pCi}{g} \right) \times EF_{ow} \left(\frac{225 \text{ days}}{\text{year}} \right) \times ED_{ow} (25 \text{ years}) \times ET_{ow} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{ow} \left(\frac{60 \text{ m}^3}{\text{day}} \right) \times \frac{1}{PEF} \left(\frac{\text{m}^3}{\text{kg}} \right) \times \left(\frac{1000 \text{ g}}{\text{kg}} \right)$$

- external exposure to ionizing radiation

$$CDI_{ow-soil-ext} (pCi\text{-year/g}) = \left(C_{soil} \left(\frac{pCi}{g} \right) \times EF_{ow} \left(\frac{225 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{ow} (25 \text{ years}) \times \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{ext-sv} (1.0) \times ACF_{ext-sv} \right)$$

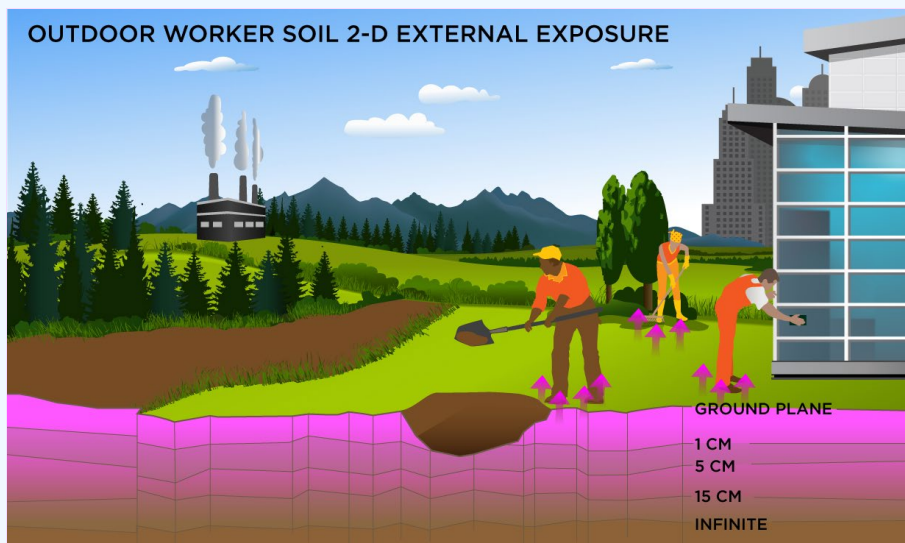
Definitions of the input variables are in [Table 1](#).

4.3.2 Outdoor Worker Soil 2-D External Exposure

This long-term receptor, exposed during the work day, is a full time employee working on-site who spends most of the workday conducting maintenance activities outdoors. The activities for this receptor (e.g., moderate digging, landscaping) typically involve on-site exposures to surface soils.

This analysis is designed to look at external exposure from contamination of different area sizes. Areas considered are 1 to 1,000,000 square meters. Isotope-specific area correction factor (ACF) were developed for this analysis.

Graphical Representation



PRG Equations

- Direct External Exposure to contamination at infinite depth

$$PRG_{ow-soil-sv} (pCi/g) = \frac{TR}{SF_{ext-sv} \left(\frac{\text{risk/year}}{pCi/g} \right) \times EF_{ow} \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{ext-sv} \times ED_{ow} (25 \text{ years}) \times ET_{ow} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{o-ext-sv}}$$

The resulting units for this recommended PRG are in pCi/g. The units are based on mass because the SF used is the soil volume for external exposure.

- Direct External Exposure to contamination 1 cm thick

$$PRG_{ow-soil-1cm} (pCi/g) = \frac{TR}{SF_{ext-1cm} \left(\frac{risk/year}{pCi/g} \right) \times EF_{ow} \left(\frac{250 \text{ days}}{year} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{ext-1cm} \times ED_{ow} (25 \text{ years}) \times ET_{ow} \left(\frac{8 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{o-ext-1cm}}$$

The resulting units for this recommended PRG are in pCi/g. The units are based on mass because the SF used is the 1cm soil volume for external exposure.

- Direct External Exposure to contamination 5 cm thick

$$PRG_{ow-soil-5cm} (pCi/g) = \frac{TR}{SF_{ext-5cm} \left(\frac{risk/year}{pCi/g} \right) \times EF_{ow} \left(\frac{250 \text{ days}}{year} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{ext-5cm} \times ED_{ow} (25 \text{ year}) \times ET_{ow} \left(\frac{8 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{o-ext-5cm}}$$

The resulting units for this recommended PRG are in pCi/g. The units are based on mass because the SF used is the 5cm soil volume for external exposure.

- Direct External Exposure to contamination 15 cm thick

$$PRG_{ow-soil-15cm} (pCi/g) = \frac{TR}{SF_{ext-15cm} \left(\frac{risk/year}{pCi/g} \right) \times EF_{ow} \left(\frac{250 \text{ days}}{year} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{ext-15cm} \times ED_{ow} (25 \text{ years}) \times ET_{ow} \left(\frac{8 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{o-ext-15cm}}$$

The resulting units for this recommended PRG are in pCi/g. The units are based on mass because the SF used is the 15cm soil volume for external exposure.

- Direct External Exposure to surface contamination

$$PRG_{ow-soil-gp} (pCi/cm^2) = \frac{TR}{SF_{ext-gp} \left(\frac{risk/year}{pCi/cm^2} \right) \times EF_{ow} \left(\frac{250 \text{ days}}{year} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{ext-gp} \times ED_{ow} (25 \text{ years}) \times ET_{ow} \left(\frac{8 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{o-ext-gp}}$$

The resulting units for this recommended PRG are in pCi/cm². The units are based on area because the SF used is the ground plane for external exposure.

Definitions of the input variables are in [Table 1](#).

CDI Equations

- Direct External Exposure to contamination at infinite depth

$$CDI_{ow-soil-sv} (pCi-year/g) = \left(\frac{C_{soil} \left(\frac{pCi}{g} \right) \times EF_{ow} \left(\frac{250 \text{ days}}{year} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{ow} (25 \text{ years}) \times ET_{ow} \left(\frac{8 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{ext-sv} (1.0) \times ACF_{ext-sv}}{1} \right)$$

- Direct External Exposure to contamination 1 cm thick

$$CDI_{ow-soil-1cm} (pCi-year/g) = \left(\frac{C_{soil} \left(\frac{pCi}{g} \right) \times EF_{ow} \left(\frac{250 \text{ days}}{year} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{ow} (25 \text{ years}) \times ET_{ow} \left(\frac{8 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{ext-1cm} (1.0) \times ACF_{ext-1cm}}{1} \right)$$

- Direct External Exposure to contamination 5 cm thick

$$CDI_{ow-soil-5cm} (pCi-year/g) = \left(\frac{C_{soil} \left(\frac{pCi}{g} \right) \times EF_{ow} \left(\frac{250 \text{ days}}{year} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{ow} (25 \text{ years}) \times ET_{ow} \left(\frac{8 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{ext-5cm} (1.0) \times ACF_{ext-5cm}}{1} \right)$$

- Direct External Exposure to contamination 15 cm thick

$$CDI_{ow-soil-15cm} (pCi\text{-year/g}) = \left(C_{soil} \left(\frac{pCi}{g} \right) \times EF_{ow} \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{ow} (25 \text{ years}) \times \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{ext-15cm} (1.0) \times ACF_{ext-15cm} \right)$$

- Direct External Exposure to surface contamination

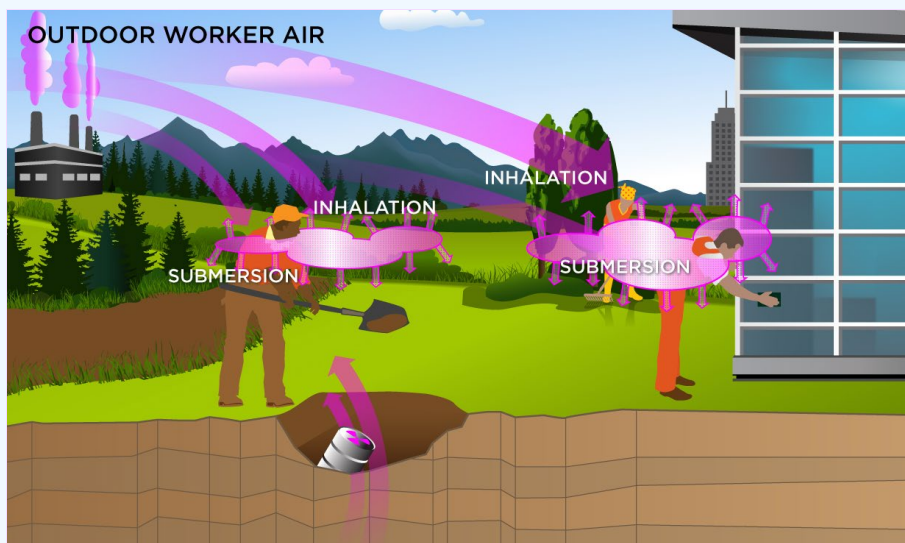
$$CDI_{ow-soil-gp} (pCi\text{-year/cm}^2) = \left(C_{soil} \left(\frac{pCi}{\text{cm}^2} \right) \times EF_{ow} \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{ow} (25 \text{ years}) \times \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{ext-gp} (1.0) \times ACF_{ext-gp} \right)$$

Definitions of the input variables are in [Table 1](#).

4.3.3 Outdoor Worker Air

This long-term receptor, exposed during the work day, is a full time employee working on-site who spends most of the workday conducting maintenance activities outdoors. The activities for this receptor (e.g., moderate digging, landscaping) typically involve on-site exposures to surface soils. The outdoor worker is assumed to be exposed to contaminants via the following pathways: inhalation of ambient air and external radiation from contaminants in ambient air.

Graphical Representation



PRG Equations

The outdoor worker ambient air land use equation, presented here, contains the following exposure routes:

- inhalation and

$$PRG_{ow-air-inh} (pCi/m^3) = \frac{TR}{SF_i \left(\frac{risk}{pCi} \right) \times EF_{ow} \left(\frac{225 \text{ days}}{\text{year}} \right) \times ED_{ow} (25 \text{ years}) \times ET_{ow} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{ow} \left(\frac{60 \text{ m}^3}{\text{day}} \right)}$$

- external exposure to ionizing radiation

$$PRG_{ow-air-sub} (pCi/m^3) = \frac{TR}{SF_{sub} \left(\frac{risk/year}{pCi/m^3} \right) \times EF_{ow} \left(\frac{250 \text{ day}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{ow} (25 \text{ years}) \times ET_{ow} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)}$$

- total

$$PRG_{ow-air-tot} (pCi/m^3) = \frac{1}{\frac{1}{PRG_{ow-air-inh}} + \frac{1}{PRG_{ow-air-sub}}}$$

In situations where the contaminant in the air is not being replenished (e.g., an accidental one-time air release from a factory), decay should be used. In situations where the contaminant in the air has

a continual source (e.g., indoor radon from radium in the soil or an operating factory or landfill cap), the equations without decay should be used. The decay function, found in section 4.10.7, can be multiplied by the ambient air equations above to acquire ambient air PRGs with decay.

Definitions of the input variables are in [Table 1](#).

CDI Equations

The outdoor worker ambient air land use equation, presented here, contains the following exposure routes:

- inhalation and

$$CDI_{ow-air-inh} (pCi) = C_{air} \left(\frac{pCi}{m^3} \right) \times EF_{ow} \left(\frac{225 \text{ days}}{\text{year}} \right) \times ED_{ow} (25 \text{ years}) \times ET_{ow} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{ow} \left(\frac{60 \text{ m}^3}{\text{day}} \right)$$

- external exposure to ionizing radiation

$$CDI_{ow-air-sub} (pCi\text{-}ye ar/m^3) = C_{air} \left(\frac{pCi}{m^3} \right) \times EF_{ow} \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{ow} (25 \text{ years}) \times ET_{ow} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)$$

Definitions of the input variables are in [Table 1](#).

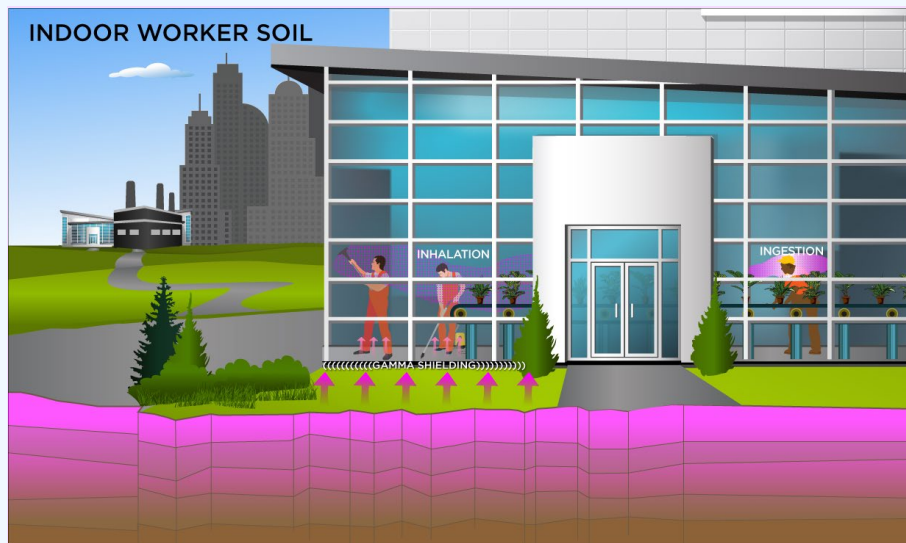
4.4 Indoor Worker

4.4.1 Indoor Worker Soil

This receptor spends most, if not all, of the workday indoors. Thus, an indoor worker has no direct contact with outdoor soils. This worker may, however, be exposed to contaminants through ingestion of contaminated soils that have been incorporated into indoor dust, external radiation from contaminants in soil, and the inhalation of contaminants present in indoor air. PRGs calculated for this receptor are expected to be protective of both workers engaged in low intensity activities such as office work and those engaged in more strenuous activity (e.g., factory or warehouse workers).

The indoor worker soil land use is not provided in the Download Area, but PRGs can be created by using the Calculator to modify the exposure parameters for the composite worker to match the equations that follow.

Graphical Representation



PRG Equations

The indoor worker soil land use equation, presented here, contains the following exposure routes:

- incidental ingestion of soil,

$$PRG_{iw-soil-ing} (pCi/g) = \frac{TR}{SF_{sa} \left(\frac{\text{risk}}{pCi} \right) \times EF_{iw} \left(\frac{250 \text{ days}}{\text{year}} \right) \times ED_{iw} (25 \text{ year}) \times IRS_{iw} \left(\frac{50 \text{ mg}}{\text{day}} \right) \times \left(\frac{g}{1000 \text{ mg}} \right)}$$

- inhalation of particulates emitted from soil, and

$$\text{PRG}_{\text{iw-soil-inh}} (\text{pCi/g}) = \frac{\text{TR}}{\text{SF}_i \left(\frac{\text{risk}}{\text{pCi}} \right) \times \text{EF}_{\text{iw}} \left(\frac{250 \text{ days}}{\text{year}} \right) \times \text{ED}_{\text{iw}} (25 \text{ years}) \times \left(\frac{1000 \text{ g}}{\text{kg}} \right) \times \text{ET}_{\text{iw}} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{IRA}_{\text{iw}} \left(\frac{60 \text{ m}^3}{\text{day}} \right) \times \frac{1}{\text{PEF} \left(\frac{\text{m}^3}{\text{kg}} \right)}}$$

- external exposure to ionizing radiation

$$\text{PRG}_{\text{iw-soil-ext}} (\text{pCi/g}) = \frac{\text{TR}}{\text{SF}_{\text{ext-sv}} \left(\frac{\text{risk/year}}{\text{pCi/g}} \right) \times \text{EF}_{\text{iw}} \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times \text{ACF}_{\text{ext-sv}} \times \text{ED}_{\text{iw}} (25 \text{ years}) \times \text{ET}_{\text{iw}} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{GSF}_{\text{i-total}}}$$

- total

$$\text{PRG}_{\text{iw-soil-tot}} (\text{pCi/g}) = \frac{1}{\frac{1}{\text{PRG}_{\text{iw-soil-ing}}} + \frac{1}{\text{PRG}_{\text{iw-soil-inh}}} + \frac{1}{\text{PRG}_{\text{iw-soil-ext}}}}$$

Definitions of the input variables are in [Table 1](#).

CDI Equations

The indoor worker soil land use equation, presented here, contains the following exposure routes:

- incidental ingestion of soil,

$$\text{CDI}_{\text{iw-soil-ing}} (\text{pCi}) = C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times \text{EF}_{\text{iw}} \left(\frac{250 \text{ days}}{\text{year}} \right) \times \text{ED}_{\text{iw}} (25 \text{ years}) \times \text{IRS}_{\text{iw}} \left(\frac{50 \text{ mg}}{\text{day}} \right) \times \left(\frac{\text{g}}{1000 \text{ mg}} \right)$$

- inhalation of particulates emitted from soil, and

$$\text{CDI}_{\text{iw-soil-inh}} (\text{pCi}) = C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times \text{EF}_{\text{iw}} \left(\frac{250 \text{ days}}{\text{year}} \right) \times \text{ED}_{\text{iw}} (25 \text{ years}) \times \text{ET}_{\text{iw}} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{IRA}_{\text{iw}} \left(\frac{60 \text{ m}^3}{\text{day}} \right) \times \frac{1}{\text{PEF} \left(\frac{\text{m}^3}{\text{kg}} \right)} \times \left(\frac{1000 \text{ g}}{\text{kg}} \right)$$

- external exposure to ionizing radiation

$$\text{CDI}_{\text{iw-soil-ext}} (\text{pCi-year/g}) = \left(\begin{array}{l} C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times \text{EF}_{\text{iw}} \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times \text{ED}_{\text{iw}} (25 \text{ years}) \times \\ \text{ET}_{\text{iw}} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{GSF}_{\text{i-total}} \times \text{ACF}_{\text{ext-sv}} \end{array} \right)$$

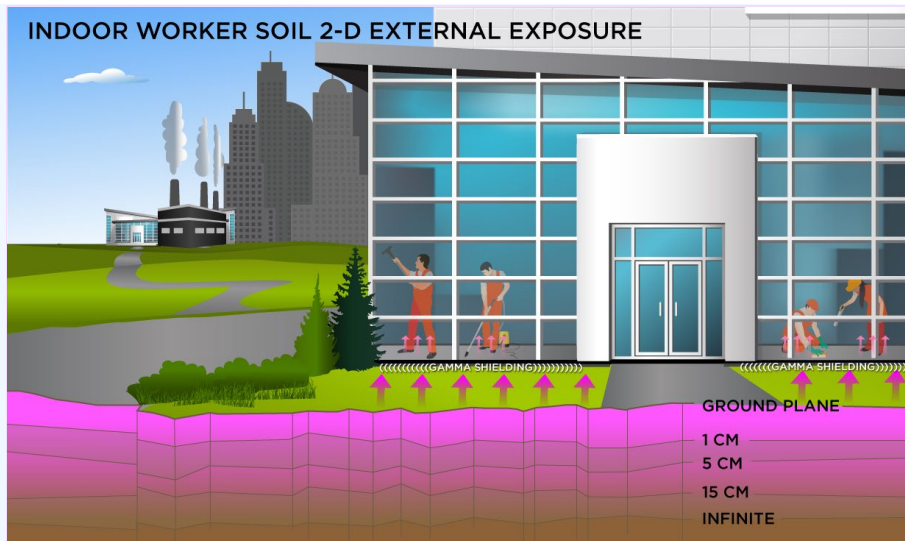
Definitions of the input variables are in [Table 1](#).

4.4.2 Indoor Worker Soil 2-D External Exposure

This receptor spends most, if not all, of the workday indoors. Thus, an indoor worker has no direct contact with outdoor soils. A gamma shielding factor is applied for this scenario to account for shielding provided by floors and foundation slabs.

This analysis is designed to look at external exposure from contamination of different area sizes. Areas considered are 1 to 1,000,000 square meters. Isotope-specific area correction factor (ACF) were developed for this analysis.

Graphical Representation



PRG Equations

- Direct External Exposure to contamination at infinite depth

$$PRG_{iw-soil-sv} (pCi/g) = \frac{TR}{SF_{ext-sv} \left(\frac{\text{risk/year}}{pCi/g} \right) \times EF_{iw} \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{ext-sv} \times ED_{iw} (25 \text{ years}) \times ET_{iw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{i-total}}$$

The resulting units for this recommended PRG are in pCi/g. The units are based on mass because the SF used is the soil volume for external exposure.

- Direct External Exposure to contamination 1 cm thick

$$PRG_{iw-soil-1cm} (pCi/g) = \frac{TR}{SF_{ext-1cm} \left(\frac{\text{risk/year}}{pCi/g} \right) \times EF_{iw} \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{ext-1cm} \times ED_{iw} (25 \text{ years}) \times ET_{iw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{i-total}}$$

The resulting units for this recommended PRG are in pCi/g. The units are based on mass because the SF used is the 1cm soil volume for external exposure.

- Direct External Exposure to contamination 5 cm thick

$$PRG_{iw-soil-5cm} (pCi/g) = \frac{TR}{SF_{ext-5cm} \left(\frac{\text{risk/year}}{pCi/g} \right) \times EF_{iw} \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{ext-5cm} \times ED_{iw} (25 \text{ years}) \times ET_{iw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{i-total}}$$

The resulting units for this recommended PRG are in pCi/g. The units are based on mass because the SF used is the 5cm soil volume for external exposure.

- Direct External Exposure to contamination 15 cm thick

$$PRG_{iw-soil-15cm} (pCi/g) = \frac{TR}{SF_{ext-15cm} \left(\frac{\text{risk/year}}{pCi/g} \right) \times EF_{iw} \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{ext-15cm} \times ED_{iw} (25 \text{ years}) \times ET_{iw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{i-total}}$$

The resulting units for this recommended PRG are in pCi/g. The units are based on mass because the SF used is the 15cm soil volume for external exposure.

- Direct External Exposure to surface contamination

$$PRG_{iw-soil-gp} \text{ (pCi/cm}^2\text{)} = \frac{TR}{SF_{ext-gp} \left(\frac{\text{risk/year}}{\text{pCi/cm}^2} \right) \times EF_{iw} \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{ext-gp} \times ED_{iw} (25 \text{ years}) \times ET_{iw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{i-total}}$$

The resulting units for this recommended PRG are in pCi/cm². The units are based on area because the SF used is the ground plane for external exposure.

Definitions of the input variables are in [Table 1](#).

CDI Equations

- Direct External Exposure to contamination at infinite depth

$$CDI_{iw-soil-sv} \text{ (pCi-year/g)} = \left(C_{soil} \left(\frac{\text{pCi}}{\text{g}} \right) \times EF_{iw} \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{iw} (25 \text{ years}) \times ET_{iw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{i-total} \times ACF_{ext-sv} \right)$$

- Direct External Exposure to contamination 1 cm thick

$$CDI_{iw-soil-1cm} \text{ (pCi-year/g)} = \left(C_{soil} \left(\frac{\text{pCi}}{\text{g}} \right) \times EF_{iw} \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{iw} (25 \text{ years}) \times ET_{iw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{i-total} \times ACF_{ext-1cm} \right)$$

- Direct External Exposure to contamination 5 cm thick

$$CDI_{iw-soil-5cm} \text{ (pCi-year/g)} = \left(C_{soil} \left(\frac{\text{pCi}}{\text{g}} \right) \times EF_{iw} \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{iw} (25 \text{ years}) \times ET_{iw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{i-total} \times ACF_{ext-5cm} \right)$$

- Direct External Exposure to contamination 15 cm thick

$$CDI_{iw-soil-15cm} \text{ (pCi-year/g)} = \left(C_{soil} \left(\frac{\text{pCi}}{\text{g}} \right) \times EF_{iw} \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{iw} (25 \text{ years}) \times ET_{iw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{i-total} \times ACF_{ext-15cm} \right)$$

- Direct External Exposure to surface contamination

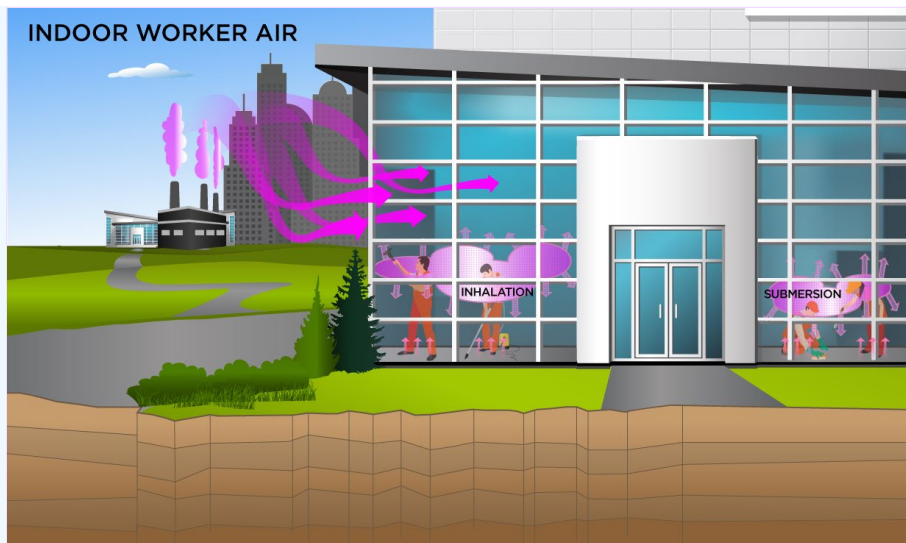
$$CDI_{iw-soil-gp} \text{ (pCi-year/cm}^2\text{)} = \left(C_{soil} \left(\frac{\text{pCi}}{\text{cm}^2} \right) \times EF_{iw} \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{iw} (25 \text{ years}) \times ET_{iw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{i-total} \times ACF_{ext-gp} \right)$$

Definitions of the input variables are in [Table 1](#).

4.4.3 Indoor Worker Air

This long-term receptor, exposed during the work day, is a full time employee working on-site who spends most, if not all, of the workday indoors. The indoor worker is assumed to be exposed to contaminants via the following pathways: inhalation of ambient air and external radiation from contaminants in ambient air.

Graphical Representation



PRG Equations

The indoor worker ambient air land use equation, presented here, contains the following exposure routes:

- inhalation and

$$PRG_{iw-air-inh} (pCi/m^3) = \frac{TR}{SF_i \left(\frac{\text{risk}}{pCi} \right) \times EF_{iw} \left(\frac{250 \text{ days}}{\text{year}} \right) \times ED_{iw} (25 \text{ years}) \times ET_{iw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{iw} \left(\frac{60 \text{ m}^3}{\text{day}} \right)}$$

- external exposure to ionizing radiation

$$PRG_{iw-air-sub} (pCi/m^3) = \frac{TR}{SF_{sub} \left(\frac{\text{risk/year}}{pCi/m^3} \right) \times EF_{iw} \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{iw} (25 \text{ years}) \times ET_{iw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)}$$

- total

$$PRG_{iw-air-tot} (pCi/m^3) = \frac{1}{\frac{1}{PRG_{iw-air-inh}} + \frac{1}{PRG_{iw-air-sub}}}$$

In situations where the contaminant in the air is not being replenished (e.g., an accidental one-time air release from a factory), decay should be used. In situations where the contaminant in the air has a continual source (e.g., indoor radon from radium in the soil or an operating factory or landfill cap), the equations without decay should be used. The decay function, found in section 4.10.7, can be multiplied by the ambient air equations above to acquire ambient air PRGs with decay.

Definitions of the input variables are in [Table 1](#).

CDI Equations

The indoor worker ambient air land use equation, presented here, contains the following exposure routes:

- inhalation and

$$CDI_{iw-air-inh} (pCi) = C_{air} \left(\frac{pCi}{m^3} \right) \times EF_{iw} \left(\frac{250 \text{ days}}{\text{year}} \right) \times ED_{iw} (25 \text{ years}) \times ET_{iw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{iw} \left(\frac{60 \text{ m}^3}{\text{day}} \right)$$

- external exposure to ionizing radiation

$$CDI_{iw-air-sub} (pCi \cdot \text{year}/m^3) = C_{air} \left(\frac{pCi}{m^3} \right) \times EF_{iw} \left(\frac{250 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{iw} (25 \text{ years}) \times ET_{iw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)$$

Definitions of the input variables are in [Table 1](#).

4.5 Construction Worker

An assessment for the construction worker scenario is described in more detail in the [supplemental soil screening guidance \(SSSG; U.S. EPA, 2002b\)](#). Examples given in the SSSG show that the time of traffic (T_t) is equivalent to EF and time of construction (T_c) is the length of project. The particulate emission factor (PEF) equations used are unique to this scenario. See Section 4.10 for further information on subchronic PEFs. The PEFs calculated in these scenarios may predict much higher air concentrations than the standard wind-driven PEFs. Two types of mechanical soil disturbance are addressed: standard vehicle traffic (unpaved) and other construction activities (wind, grading, dozing, tilling, and excavating). In general, the intake and contact rates are all greater than the outdoor worker. Exhibit 5-1 in the supplemental soil screening guidance presents the exposure parameters.

4.5.1 Construction Worker Soil Exposure to Unpaved Road Traffic

This short-term receptor is exposed during the work day to vehicles suspending dust in the air. The activities for this receptor (e.g., trenching, excavating) typically involve on-site exposures to surface soils. The construction worker is expected to have an elevated soil ingestion rate (330 mg per day) and is assumed to be exposed to contaminants via the following pathways: incidental ingestion of soil, external radiation from contaminants in soil, and inhalation of fugitive dust. The only difference between this construction worker and the one described in section 4.5.4 is that this construction worker uses a different PEF.

The construction worker soil land use is not provided in the Download Area, but PRGs can be created by using the Calculator. The construction land use is described in the [supplemental soil screening guidance](#). This land use is limited to an exposure duration of 1 year and is, thus, subchronic. Other unique aspects of this scenario are that the PEF is based on mechanical disturbance of the soil. Two types of mechanical soil disturbance are addressed: standard vehicle traffic and other than standard vehicle traffic (e.g. wind, grading, dozing, tilling, and excavating). In general, the intakes and contact rates are all greater than the outdoor worker. Exhibit 5-1 in the [supplemental soil screening guidance](#) presents the exposure parameters.

Graphical Representation



PRG Equations

The construction worker soil land use equations, presented here, contain the following exposure routes:

- incidental ingestion of soil,

$$PRG_{cw-soil-ing} (pCi/g) = \frac{TR}{SF_{sa} \left(\frac{risk}{pCi} \right) \times EF_{cw} \left(\frac{EW_{cw} \text{ 50 weeks}}{\text{year}} \times \frac{DW_{cw} \text{ 5 days}}{\text{week}} \right) \times ED_{cw} (1 \text{ years}) \times IRS_{cw} \left(\frac{330 \text{ mg}}{\text{day}} \right) \times \left(\frac{g}{1000 \text{ mg}} \right)}$$

- inhalation of particulates emitted from soil, and

$$PRG_{cw-soil-inh} (pCi/g) = \frac{TR}{SF_{sa} \left(\frac{risk}{pCi} \right) \times EF_{cw} \left(\frac{EW_{cw} \text{ 50 weeks}}{\text{year}} \times \frac{DW_{cw} \text{ 5 days}}{\text{week}} \right) \times ED_{cw} (1 \text{ years}) \times ET_{cw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{cw} \left(\frac{60 \text{ m}^3}{\text{day}} \right) \times \frac{1}{PEF_{sc} \left(\frac{\text{m}^3}{\text{kg}} \right)} \times \left(\frac{1000 \text{ g}}{\text{kg}} \right)}$$

- external exposure to ionizing radiation

$$PRG_{cw-soil-ext} (pCi/g) = \frac{TR}{SF_{ext-sv} \left(\frac{risk/year}{pCi/g} \right) \times EF_{cw} \left(\frac{EW_{cw} \ 50 \text{ weeks}}{year} \times \frac{DW_{cw} \ 5 \text{ days}}{week} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{cw} (1 \text{ years}) \times ACF_{ext-sv} \times ET_{cw} \left(\frac{8 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{o-ext-sv}}$$

- total

$$PRG_{cw-soil-tot} (pCi/g) = \frac{1}{\frac{1}{PRG_{cw-soil-ing}} + \frac{1}{PRG_{cw-soil-inh}} + \frac{1}{PRG_{cw-soil-ext}}}$$

Definitions of the input variables are in [Table 1](#).

CDI Equations

The construction worker soil land use equations, presented here, contain the following exposure routes:

- incidental ingestion of soil,

$$CDI_{cw-soil-ing} (pCi) = C_{soil} \left(\frac{pCi}{g} \right) \times EF_{cw} \left(\frac{EW_{cw} \ 50 \text{ weeks}}{year} \times \frac{DW_{cw} \ 5 \text{ days}}{week} \right) \times ED_{cw} (1 \text{ year}) \times IRS_{cw} \left(\frac{330 \text{ mg}}{day} \right) \times \left(\frac{g}{1000 \text{ mg}} \right)$$

- inhalation of particulates emitted from soil, and

$$CDI_{cw-soil-inh} (pCi) = \left(C_{soil} \left(\frac{pCi}{g} \right) \times EF_{cw} \left(\frac{EW_{cw} \ 50 \text{ weeks}}{year} \times \frac{DW_{cw} \ 5 \text{ days}}{week} \right) \times ED_{cw} (1 \text{ year}) \times ET_{cw} \left(\frac{8 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{cw} \left(\frac{60 \text{ m}^3}{day} \right) \times \frac{1}{PEF_{sc} \left(\frac{\text{m}^3}{kg} \right)} \times \left(\frac{1000 \text{ g}}{kg} \right) \right)$$

- external exposure to ionizing radiation

$$CDI_{cw-soil-ext} (pCi-year/g) = \left(C_{soil} \left(\frac{pCi}{g} \right) \times EF_{cw} \left(\frac{EW_{cw} \ 50 \text{ weeks}}{year} \times \frac{DW_{cw} \ 5 \text{ days}}{week} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{cw} (1 \text{ year}) \times ET_{cw} \left(\frac{8 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{ext-sv} (1.0) \times ACF_{ext-sv} \right)$$

Definitions of the input variables are in [Table 1](#).

4.5.2 Construction Worker Soil Exposure to Unpaved Road Traffic 2-D External Exposure

This short-term receptor is exposed during the work day to heavy vehicles suspending dust in the air. The activities for this receptor (e.g., trenching, excavating, wind, grading, dozing, and tilling) typically involve on-site exposures to surface soils.

This analysis is designed to look at external exposure from contamination of different area sizes. Areas considered are 1 to 1,000,000 square meters. Isotope-specific area correction factor (ACF) were developed for this analysis.

Graphical Representation



PRG Equations

- Direct External Exposure to contamination at infinite depth

$$PRG_{cw-soil-sv} \text{ (pCi/g)} = \frac{TR}{SF_{ext-sv} \left(\frac{\text{risk/year}}{\text{pCi/g}} \right) \times EF_{cw} \left(\frac{EW_{cw}}{\text{year}} \times \frac{50 \text{ weeks}}{\text{year}} \times \frac{DW_{cw}}{\text{week}} \times \frac{5 \text{ days}}{\text{week}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{cw} (1 \text{ years}) \times ACF_{ext-sv} \times ET_{cw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{o-ext-sv}}$$

The resulting units for this recommended PRG are in pCi/g. The units are based on mass because the SF used is the soil volume for external exposure.

- Direct External Exposure to contamination 1 cm thick

$$PRG_{cw-soil-1cm} \text{ (pCi/g)} = \frac{TR}{SF_{ext-1cm} \left(\frac{\text{risk/year}}{\text{pCi/g}} \right) \times EF_{cw} \left(\frac{EW_{cw}}{\text{year}} \times \frac{50 \text{ weeks}}{\text{year}} \times \frac{DW_{cw}}{\text{week}} \times \frac{5 \text{ days}}{\text{week}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{cw} (1 \text{ years}) \times ACF_{ext-1cm} \times ET_{cw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{o-ext-1cm}}$$

The resulting units for this recommended PRG are in pCi/g. The units are based on mass because the SF used is the 1cm soil volume for external exposure.

- Direct External Exposure to contamination 5 cm thick

$$PRG_{cw-soil-5cm} \text{ (pCi/g)} = \frac{TR}{SF_{ext-5cm} \left(\frac{\text{risk/year}}{\text{pCi/g}} \right) \times EF_{cw} \left(\frac{EW_{cw}}{\text{year}} \times \frac{50 \text{ weeks}}{\text{year}} \times \frac{DW_{cw}}{\text{week}} \times \frac{5 \text{ days}}{\text{week}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{cw} (1 \text{ years}) \times ACF_{ext-5cm} \times ET_{cw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{o-ext-5cm}}$$

The resulting units for this recommended PRG are in pCi/g. The units are based on mass because the SF used is the 5cm soil volume for external exposure.

- Direct External Exposure to contamination 15 cm thick

$$PRG_{cw-soil-15cm} \text{ (pCi/g)} = \frac{TR}{SF_{ext-15cm} \left(\frac{\text{risk/year}}{\text{pCi/g}} \right) \times EF_{cw} \left(\frac{EW_{cw}}{\text{year}} \times \frac{50 \text{ weeks}}{\text{year}} \times \frac{DW_{cw}}{\text{week}} \times \frac{5 \text{ days}}{\text{week}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{cw} (1 \text{ years}) \times ACF_{ext-15cm} \times ET_{cw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{o-ext-15cm}}$$

The resulting units for this recommended PRG are in pCi/g. The units are based on mass because the SF used is the 15cm soil volume for external exposure.

- Direct External Exposure to surface contamination

$$PRG_{cw-soil-gp} (pCi/cm^2) = \frac{TR}{SF_{ext-gp} \left(\frac{risk/year}{pCi/cm^2} \right) \times EF_{cw} \left(EW_{cw} \frac{50 \text{ weeks}}{year} \times DW_{cw} \frac{5 \text{ days}}{week} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{cw} (1 \text{ years}) \times ACF_{ext-gp} \times ET_{cw} \left(\frac{8 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{o-ext-gp}}$$

The resulting units for this recommended PRG are in pCi/cm². The units are based on area because the SF used is the ground plane for external exposure.

Definitions of the input variables are in [Table 1](#).

CDI Equations

- Direct External Exposure to contamination at infinite depth

$$CDI_{cw-soil-sv} (pCi\text{-}year/g) = \left(\begin{array}{l} C_{soil} \left(\frac{pCi}{g} \right) \times EF_{cw} \left(EW_{cw} \frac{50 \text{ weeks}}{year} \times DW_{cw} \frac{5 \text{ days}}{week} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times \\ ED_{cw} (1 \text{ year}) \times ET_{cw} \left(\frac{8 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{ext-sv} (1.0) \times ACF_{ext-sv} \end{array} \right)$$

- Direct External Exposure to contamination 1 cm thick

$$CDI_{cw-soil-1cm} (pCi\text{-}year/g) = \left(\begin{array}{l} C_{soil} \left(\frac{pCi}{g} \right) \times EF_{cw} \left(EW_{cw} \frac{50 \text{ weeks}}{year} \times DW_{cw} \frac{5 \text{ days}}{week} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times \\ ED_{cw} (1 \text{ year}) \times ET_{cw} \left(\frac{8 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{ext-1cm} (1.0) \times ACF_{ext-1cm} \end{array} \right)$$

- Direct External Exposure to contamination 5 cm thick

$$CDI_{cw-soil-5cm} (pCi\text{-}year/g) = \left(\begin{array}{l} C_{soil} \left(\frac{pCi}{g} \right) \times EF_{cw} \left(EW_{cw} \frac{50 \text{ weeks}}{year} \times DW_{cw} \frac{5 \text{ days}}{week} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times \\ ED_{cw} (1 \text{ year}) \times ET_{cw} \left(\frac{8 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{ext-5cm} (1.0) \times ACF_{ext-5cm} \end{array} \right)$$

- Direct External Exposure to contamination 15 cm thick

$$CDI_{cw-soil-15cm} (pCi\text{-}year/g) = \left(\begin{array}{l} C_{soil} \left(\frac{pCi}{g} \right) \times EF_{cw} \left(EW_{cw} \frac{50 \text{ weeks}}{year} \times DW_{cw} \frac{5 \text{ days}}{week} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times \\ ED_{cw} (1 \text{ years}) \times ET_{cw} \left(\frac{8 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{ext-15cm} (1.0) \times ACF_{ext-15cm} \end{array} \right)$$

- Direct External Exposure to surface contamination

$$CDI_{cw-soil-gp} (pCi\text{-}year/cm^2) = \left(\begin{array}{l} C_{soil} \left(\frac{pCi}{cm^2} \right) \times EF_{cw} \left(EW_{cw} \frac{50 \text{ weeks}}{year} \times DW_{cw} \frac{5 \text{ days}}{week} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times \\ ED_{cw} (1 \text{ year}) \times ET_{cw} \left(\frac{8 \text{ hours}}{day} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{ext-gp} (1.0) \times ACF_{ext-gp} \end{array} \right)$$

Definitions of the input variables are in [Table 1](#).

4.5.3 Construction Worker Air

This short-term receptor is exposed during the work day to heavy vehicles suspending dust in the air. The activities for this receptor (e.g., trenching, excavating, wind, grading, dozing, and tilling) typically involve on-site exposures to surface soils. The construction worker is assumed to be exposed to contaminants via the following pathways: inhalation of ambient air and external radiation from contaminants in ambient air.

Graphical Representation



PRG Equations

The composite worker ambient air land use equation, presented here, contains the following exposure routes:

- inhalation and

$$PRG_{cw-air-inh} \left(pCi/m^3 \right) = \frac{TR}{SF_i \left(\frac{risk}{pCi} \right) \times EF_{cw} \left(EW_{cw} \frac{50 \text{ weeks}}{\text{year}} \times DW_{cw} \frac{5 \text{ days}}{\text{week}} \right) \times ED_{cw} (1 \text{ years}) \times ET_{cw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{cw} \left(\frac{60 \text{ m}^3}{\text{day}} \right)}$$

- external exposure to ionizing radiation

$$PRG_{cw-air-sub} \left(pCi/m^3 \right) = \frac{TR}{SF_{sub} \left(\frac{risk/year}{pCi/m^3} \right) \times EF_{cw} \left(EW_{cw} \frac{50 \text{ weeks}}{\text{year}} \times DW_{cw} \frac{5 \text{ days}}{\text{week}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{cw} (1 \text{ years}) \times ET_{cw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)}$$

- total

$$PRG_{cw-air-tot} \left(pCi/m^3 \right) = \frac{1}{\frac{1}{PRG_{cw-air-inh}} + \frac{1}{PRG_{cw-air-sub}}}$$

In situations where the contaminant in the air is not being replenished (e.g., an accidental one-time air release from a factory), decay should be used. In situations where the contaminant in the air has a continual source (e.g., indoor radon from radium in the soil or an operating factory or landfill cap), the equations without decay should be used. The decay function, found in section 4.10.7, can be multiplied by the ambient air equations above to acquire ambient air PRGs with decay.

Definitions of the input variables are in [Table 1](#).

CDI Equations

The composite worker ambient air land use equation, presented here, contains the following exposure routes:

- inhalation and

$$CDI_{cw-air-inh} (pCi) = \left[C_{air} \left(\frac{pCi}{m^3} \right) \times EF_{cw} \left(EW_{cw} \frac{50 \text{ weeks}}{\text{year}} \times DW_{cw} \frac{5 \text{ days}}{\text{week}} \right) \times ED_{cw} (1 \text{ year}) \times ET_{cw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{cw} \left(\frac{60 \text{ m}^3}{\text{day}} \right) \right]$$

- external exposure to ionizing radiation

$$CDI_{cw-air-sub}(pCi) = \left(C_{air} \left(\frac{pCi}{m^3} \right) \times EF_{cw} \left(\frac{EW_{cw} \text{ 50 weeks}}{\text{year}} \times \frac{DW_{cw} \text{ 5 days}}{\text{week}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times \right. \\ \left. ED_{cw} (1 \text{ year}) \times ET_{cw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0) \right)$$

Definitions of the input variables are in [Table 1](#).

4.5.4 Construction Worker Soil Exposure to Other Construction Activities

This short-term receptor is exposed during the work day to heavy vehicles suspending dust in the air. The activities for this receptor (e.g., dozing, grading, tilling, dumping, and excavating) typically involve on-site exposures to surface soils. The construction worker is expected to have an elevated soil ingestion rate (330 mg per day) and is assumed to be exposed to contaminants via the following pathways: incidental ingestion of soil, external radiation from contaminants in soil, and inhalation of fugitive dust. The only difference between this construction worker and the one described in section 4.5.1 is that this construction worker uses a different PEF.

The construction worker soil land use is not provided in the Download Area, but PRGs can be created by using the Calculator. The construction land use is described in the [supplemental soil screening guidance](#). This land use is limited to an exposure duration of 1 year and is, thus, subchronic. Other unique aspects of this scenario are that the PEF is based on mechanical disturbance of the soil. Two types of mechanical soil disturbance are addressed: standard vehicle traffic and other than standard vehicle traffic (e.g. wind, grading, dozing, tilling, and excavating). In general, the intakes and contact rates are all greater than the outdoor worker. Exhibit 5-1 in the [supplemental soil screening guidance](#) presents the exposure parameters.

Graphical Representation



PRG Equations

The construction worker soil land use equations, presented here, contain the following exposure routes:

- incidental ingestion of soil,

$$PRG_{cw-soil-ing-sa}(pCi/g) = \frac{TR}{SF_{sa} \left(\frac{\text{risk}}{pCi} \right) \times EF_{cw} \left(\frac{EW_{cw} \text{ 50 weeks}}{\text{year}} \times \frac{DW_{cw} \text{ 5 days}}{\text{week}} \right) \times ED_{cw} (1 \text{ years}) \times IRS_{cw} \left(\frac{330 \text{ mg}}{\text{day}} \right) \times \left(\frac{\text{g}}{1000 \text{ mg}} \right)}$$

- inhalation of particulates emitted from soil, and

$$PRG_{cw-soil-inh-sa}(pCi/g) = \frac{TR}{SF_{i} \left(\frac{\text{risk}}{pCi} \right) \times EF_{cw} \left(\frac{EW_{cw} \text{ 50 weeks}}{\text{year}} \times \frac{DW_{cw} \text{ 5 days}}{\text{week}} \right) \times ED_{cw} (1 \text{ years}) \times ET_{cw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{cw} \left(\frac{60 \text{ m}^3}{\text{day}} \right) \times \frac{1}{PEF'_{sc} \left(\frac{\text{m}^3}{\text{kg}} \right)} \times \left(\frac{1000 \text{ g}}{\text{kg}} \right)}$$

- external exposure to ionizing radiation

$$PRG_{\text{cw-soil-ext-sa}}(\text{pCi/g}) = \frac{TR}{SF_{\text{ext-sv}} \left(\frac{\text{risk/year}}{\text{pCi/g}} \right) \times EF_{\text{cw}} \left(EW_{\text{cw}} \frac{50 \text{ weeks}}{\text{year}} \times DW_{\text{cw}} \frac{5 \text{ days}}{\text{week}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{\text{cw}} (1 \text{ year}) \times ACF_{\text{ext-sv}} \times ET_{\text{cw}} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{o-ext-sv}}}$$

- total

$$PRG_{\text{cw-soil-tot-sa}}(\text{pCi/g}) = \frac{1}{PRG_{\text{cw-soil-ing-sa}}} + \frac{1}{PRG_{\text{cw-soil-inh-sa}}} + \frac{1}{PRG_{\text{cw-soil-ext-sa}}}$$

Definitions of the input variables are in [Table 1](#).

CDI Equations

The construction worker soil land use equations, presented here, contain the following exposure routes:

- incidental ingestion of soil,

$$CDI_{\text{cw-soil-ing-sa}}(\text{pCi}) = C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times EF_{\text{cw}} \left(EW_{\text{cw}} \frac{50 \text{ weeks}}{\text{year}} \times DW_{\text{cw}} \frac{5 \text{ days}}{\text{week}} \right) \times ED_{\text{cw}} (1 \text{ year}) \times IRS_{\text{cw}} \left(\frac{330 \text{ mg}}{\text{day}} \right) \times \left(\frac{\text{g}}{1000 \text{ mg}} \right)$$

- inhalation of particulates emitted from soil, and

$$CDI_{\text{cw-soil-inh-sa}}(\text{pCi}) = \left(C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times EF_{\text{cw}} \left(EW_{\text{cw}} \frac{50 \text{ weeks}}{\text{year}} \times DW_{\text{cw}} \frac{5 \text{ days}}{\text{week}} \right) \times ED_{\text{cw}} (1 \text{ year}) \times ET_{\text{cw}} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{\text{cw}} \left(\frac{60 \text{ m}^3}{\text{day}} \right) \times \frac{1}{PEF'_{\text{sc}}} \left(\frac{\text{m}^3}{\text{kg}} \right) \times \left(\frac{1000 \text{ g}}{\text{kg}} \right) \right)$$

- external exposure to ionizing radiation

$$CDI_{\text{cw-soil-ext-sa}}(\text{pCi-ye ar/g}) = \left(C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times EF_{\text{cw}} \left(EW_{\text{cw}} \frac{50 \text{ weeks}}{\text{year}} \times DW_{\text{cw}} \frac{5 \text{ days}}{\text{week}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{\text{cw}} (1 \text{ year}) \times ET_{\text{cw}} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{ext-sv}} (1.0) \times ACF_{\text{ext-sv}} \right)$$

Definitions of the input variables are in [Table 1](#).

4.5.5 Construction Worker Soil Exposure to Other Construction Activities 2-D External Exposure

This assessment is the same as Unpaved Roads.

4.5.6 Construction Worker Air from Exposure to Other Construction Activities

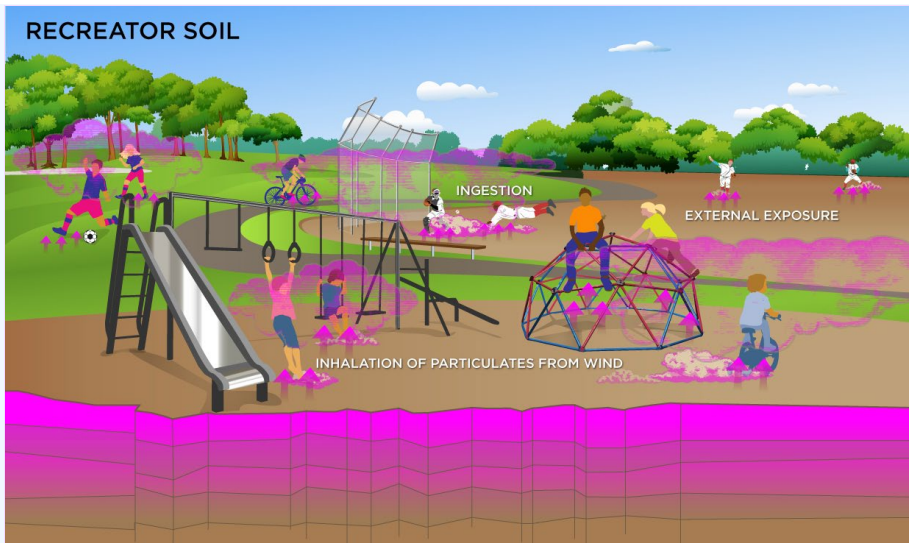
This assessment is the same as Unpaved Roads.

4.6 Recreator

4.6.1 Recreator Soil

This receptor spends time outside involved in recreational activities. The recreator is assumed to be exposed to contaminants via the following pathways: incidental ingestion of soil, dermal contact with contaminants in soil, and inhalation of volatiles and fugitive dust. There are no default PRGs for this scenario, only site-specific.

Graphical Representation



PRG Equations

- incidental ingestion of soil

$$PRG_{rec-soil-ing} (pCi/g) = \frac{TR}{SF_s \left(\frac{risk}{pCi} \right) \times IFS_{rec-adj} (mg) \times \left(\frac{g}{1000 mg} \right)}$$

where:

$$IFS_{rec-adj} (mg) = \left(\left(EF_{rec-c} \left(\frac{days}{year} \right) \times ED_{rec-c} (years) \times IRS_{rec-c} \left(\frac{200 mg}{day} \right) \right) + \left(EF_{rec-a} \left(\frac{days}{year} \right) \times ED_{rec-a} (years) \times IRS_{rec-a} \left(\frac{100 mg}{day} \right) \right) \right)$$

- inhalation of particulates emitted from soil

$$PRG_{rec-soil-inh} (pCi/g) = \frac{TR}{SF_i \left(\frac{risk}{pCi} \right) \times IFA_{rec-adj} (m^3) \times \frac{1}{PEF \left(\frac{m^3}{kg} \right)} \times \left(\frac{1000 g}{kg} \right)}$$

where:

$$IFA_{rec-adj} (m^3) = \left(\left(EF_{rec-c} \left(\frac{days}{year} \right) \times ED_{rec-c} (years) \times ET_{rec-c} \left(\frac{hours}{day} \right) \times \left(\frac{1 day}{24 hours} \right) \times IRA_{rec-c} \left(\frac{10 m^3}{day} \right) \right) + \left(EF_{rec-a} \left(\frac{days}{year} \right) \times ED_{rec-a} (years) \times ET_{rec-a} \left(\frac{hours}{day} \right) \times \left(\frac{1 day}{24 hours} \right) \times IRA_{rec-a} \left(\frac{20 m^3}{day} \right) \right) \right)$$

- external exposure to ionizing radiation

$$PRG_{rec-soil-ext} (pCi/g) = \frac{TR}{SF_{ext-sv} \left(\frac{risk/year}{pCi/g} \right) \times EF_{rec} \left(\frac{days}{year} \right) \times \left(\frac{1 year}{365 days} \right) \times ACF_{ext-sv} \times ED_{rec} (years) \times ET_{rec} \left(\frac{hours}{day} \right) \times \left(\frac{1 day}{24 hours} \right) \times GSF_{o-ext-sv}}$$

- consumption of land game - combined soil and biota

$$PRG_{rec-soil-ing-game} (pCi/g) = \frac{PRG_{rec-game-ing} (pCi/g)}{TF_{game} \left(\frac{day}{kg} \right) \times \left[\left(\frac{Q_{p-game} \left(\frac{kg}{day} \right) \times f_{p-game} (1) \times f_{s-game} (1) \times (R_{upp} + R_{es}) \right) + \left(\frac{Q_{s-game} \left(\frac{kg}{day} \right) \times f_{p-game} (1)} \right) \right]}$$

where:

$$R_{upp} = B_v \frac{(pCi / g-dry plant)}{dry (pCi / g-dry soil)} ; R_{es} = MLF_{pasture} \left(\frac{0.25 g-dry soil}{g-dry plant} \right)$$

The transfer factor for game is the same transfer factor used for beef.

consumption of fowl - combined soil and biota

$$PRG_{rec-soil-ing-fowl} (pCi/g) = \frac{PRG_{rec-fowl-ing} (pCi/g)}{TF_{fowl} \left(\frac{day}{kg} \right) \times \left[\left(Q_{p-fowl} \left(\frac{kg}{day} \right) \times f_{p-fowl} (l) \times f_{s-fowl} (l) \times (R_{upp} + R_{es}) \right) + \left(Q_{s-fowl} \left(\frac{kg}{day} \right) \times f_{p-fowl} (l) \right) \right]}$$

where:

$$R_{upp} = Bv_{dry} \left(\frac{pCi / g-dry plant}{pCi / g-dry soil} \right); R_{es} = MLF_{pasture} \left(\frac{0.25 g-dry soil}{g-dry plant} \right)$$

The transfer factor for fowl is the same transfer factor used for poultry.

- total

$$PRG_{rec-soil-tot} (pCi/g) = \frac{1}{\frac{1}{PRG_{rec-soil-ing}} + \frac{1}{PRG_{rec-soil-inh}} + \frac{1}{PRG_{rec-soil-ext}} + \frac{1}{PRG_{rec-soil-ing-game}} + \frac{1}{PRG_{rec-soil-ing-fowl}}}$$

A number of studies have shown that inadvertent ingestion of soil is common among children 6 years old and younger (Calabrese et al. 1989, Davis et al. 1990, Van Wijnen et al. 1990). Therefore, the dose method uses an age-adjusted soil ingestion factor that takes into account the difference in daily soil ingestion rates and exposure duration for children from 1 to 6 years old and others from 7 to 26 years old. This health-protective approach is chosen to take into account the higher daily rates of soil ingestion in children as well as the longer duration of exposure that is anticipated for a long-term resident. For more on this method, see [RAGS Part B](#).

Age-adjusted intake factors are also used for inhalation of particulates emitted from soil and consumption of produce. These equations are also presented in the above equations.

Definitions of the input variables are in [Table 1](#).

CDI Equations

- incidental ingestion of soil

$$CDI_{rec-soil-ing} (pCi) = C_{soil} \left(\frac{pCi}{g} \right) \times IFS_{rec-adj} (mg) \times \left(\frac{g}{1000 mg} \right)$$

where:

$$IFS_{rec-adj} (mg) = \left(\left(EF_{rec-c} \left(\frac{days}{year} \right) \times ED_{rec-c} (years) \times IRS_{rec-c} \left(\frac{200 mg}{day} \right) \right) + \left(EF_{rec-a} \left(\frac{days}{year} \right) \times ED_{rec-a} (years) \times IRS_{rec-a} \left(\frac{100 mg}{day} \right) \right) \right)$$

- inhalation of particulates emitted from soil

$$CDI_{rec-soil-inh} (pCi) = C_{soil} \left(\frac{pCi}{g} \right) \times IFA_{rec-adj} (m^3) \times \frac{1}{PEF \left(\frac{m^3}{kg} \right)} \times \left(\frac{1000 g}{kg} \right)$$

where:

$$IFA_{rec-adj} (m^3) = \left(\left(EF_{rec-c} \left(\frac{days}{year} \right) \times ED_{rec-c} (years) \times ET_{rec-c} \left(\frac{hours}{day} \right) \times \left(\frac{1 day}{24 hours} \right) \times IRA_{rec-c} \left(\frac{10 m^3}{day} \right) \right) + \left(EF_{rec-a} \left(\frac{days}{year} \right) \times ED_{rec-a} (years) \times ET_{rec-a} \left(\frac{hours}{day} \right) \times \left(\frac{1 day}{24 hours} \right) \times IRA_{rec-a} \left(\frac{20 m^3}{day} \right) \right) \right)$$

- external exposure to ionizing radiation

$$CDI_{rec-soil-ext} (pCi-year/g) = C_{soil} \left(\frac{pCi}{g} \right) \times EF_{rec} \left(\frac{days}{year} \right) \times \left(\frac{1 year}{365 days} \right) \times ED_{rec} (years) \times ET_{rec} \left(\frac{hour}{day} \right) \times \left(\frac{1 day}{24 hours} \right) \times GSF_{ext-sv} \times ACF_{ext-sv}$$

- consumption of land game - combined soil and biota

$$CDI_{rec-soil-ing-game} (pCi) = \left\{ C_{soil} \left(\frac{pCi}{g} \right) \times IRGL_{game} \left(\frac{g}{day} \right) \times EF_{rec} \left(\frac{days}{year} \right) \times ED_{rec} (years) \times CF_{rec-game} (1) \times \left[TF_{game} \left(\frac{day}{kg} \right) \times \left[\left(Q_{p-game} \left(\frac{kg}{day} \right) \times f_{p-game} (1) \times f_{s-game} (1) \times (R_{upp} + R_{es}) \right) + \left(Q_{s-game} \left(\frac{kg}{day} \right) \times f_{p-game} (1) \right) \right] \right\}$$

where:

$$R_{upp} = Bv_{dry} \left(\frac{pCi / g-dry plant}{pCi / g-dry soil} \right) ; R_{es} = MLF_{pasture} \left(\frac{0.25 g-dry soil}{g-dry plant} \right)$$

The transfer factor for game is the same transfer factor used for beef.

- consumption of fowl - combined soil and biota

$$CDI_{rec-soil-ing-fowl} (pCi) = \left\{ C_{soil} \left(\frac{pCi}{g} \right) \times IRGF_{fowl} \left(\frac{g}{day} \right) \times EF_{rec} \left(\frac{days}{year} \right) \times ED_{rec} (years) \times CF_{rec-fowl} (1) \times \left[TF_{fowl} \left(\frac{day}{kg} \right) \times \left[\left(Q_{p-fowl} \left(\frac{kg}{day} \right) \times f_{p-fowl} (1) \times f_{s-fowl} (1) \times (R_{upp} + R_{es}) \right) + \left(Q_{s-fowl} \left(\frac{kg}{day} \right) \times f_{p-fowl} (1) \right) \right] \right\}$$

where:

$$R_{upp} = Bv_{dry} \left(\frac{pCi / g-dry plant}{pCi / g-dry soil} \right) ; R_{es} = MLF_{pasture} \left(\frac{0.25 g-dry soil}{g-dry plant} \right)$$

The transfer factor for fowl is the same transfer factor used for poultry.

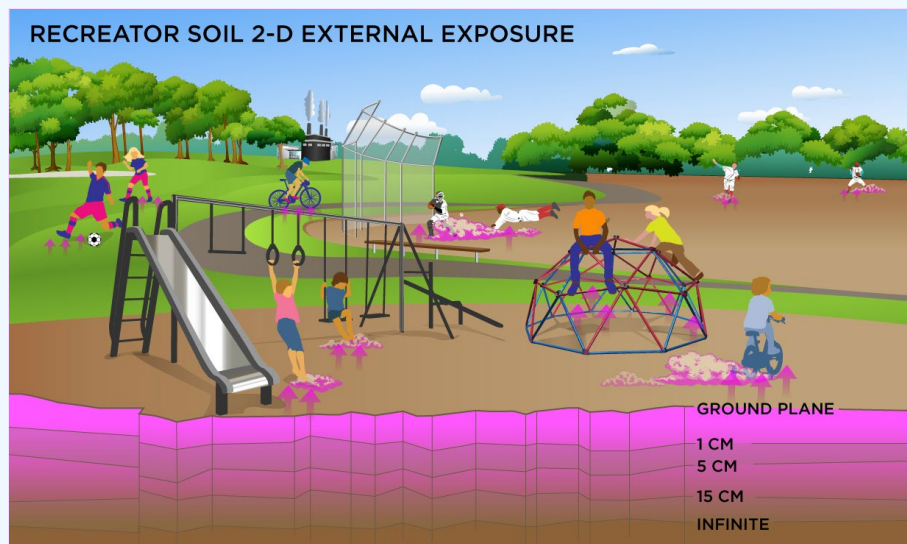
Definitions of the input variables are in [Table 1](#).

4.6.2 Recreator Soil 2-D External Exposure

This receptor spends time outside involved in recreational activities. There are no default PRGs for this scenario, only site-specific.

This analysis is designed to look at external exposure from contamination of different area sizes. Areas considered are 1 to 1,000,000 square meters. Isotope-specific area correction factor (ACF) were developed for this analysis.

Graphical Representation



PRG Equations

- Direct External Exposure to contamination at infinite depth

$$PRG_{\text{rec-soil-sv}} (\text{pCi/g}) = \frac{TR}{SF_{\text{ext-sv}} \left(\frac{\text{risk/year}}{\text{pCi/g}} \right) \times EF_{\text{rec}} \left(\frac{\text{days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{\text{ext-sv}} \times ED_{\text{rec}} (\text{years}) \times ET_{\text{rec}} \left(\frac{\text{hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{o-ext-sv}}}$$

- Direct External Exposure to contamination 1 cm thick

$$PRG_{\text{rec-soil-1cm}} (\text{pCi/g}) = \frac{TR}{SF_{\text{ext-1cm}} \left(\frac{\text{risk/year}}{\text{pCi/g}} \right) \times EF_{\text{rec}} \left(\frac{\text{days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{\text{ext-1cm}} \times ED_{\text{rec}} (\text{years}) \times ET_{\text{rec}} \left(\frac{\text{hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{o-ext-1cm}}$$

- Direct External Exposure to contamination 5 cm thick

$$PRG_{\text{rec-soil-5cm}} (\text{pCi/g}) = \frac{TR}{SF_{\text{ext-5cm}} \left(\frac{\text{risk/year}}{\text{pCi/g}} \right) \times EF_{\text{rec}} \left(\frac{\text{days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{\text{ext-5cm}} \times ED_{\text{rec}} (\text{years}) \times ET_{\text{rec}} \left(\frac{\text{hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{o-ext-5cm}}$$

- Direct External Exposure to contamination 15 cm thick

$$PRG_{\text{rec-soil-15cm}} (\text{pCi/g}) = \frac{TR}{SF_{\text{ext-15cm}} \left(\frac{\text{risk/year}}{\text{pCi/g}} \right) \times EF_{\text{rec}} \left(\frac{\text{days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{\text{ext-15cm}} \times ED_{\text{rec}} (\text{years}) \times ET_{\text{rec}} \left(\frac{\text{hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{o-ext-15cm}}$$

- Direct External Exposure to surface contamination

$$PRG_{\text{rec-soil-gp}} (\text{pCi/g}) = \frac{TR}{SF_{\text{ext-gp}} \left(\frac{\text{risk/year}}{\text{pCi/g}} \right) \times EF_{\text{rec}} \left(\frac{\text{days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ACF_{\text{ext-gp}} \times ED_{\text{rec}} (\text{years}) \times ET_{\text{rec}} \left(\frac{\text{hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{o-ext-gp}}$$

Definitions of the input variables are in [Table 1](#).

CDI Equations

- Direct External Exposure to contamination at infinite depth

$$CDI_{\text{rec-soil-sv}} (\text{pCi-year/g}) = C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times EF_{\text{rec}} \left(\frac{\text{days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{\text{rec}} (\text{years}) \times ET_{\text{rec}} \left(\frac{\text{hour}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{ext-sv}} \times ACF_{\text{ext-sv}}$$

- Direct External Exposure to contamination 1 cm thick

$$CDI_{\text{rec-soil-1cm}} (\text{pCi-year/g}) = C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times EF_{\text{rec}} \left(\frac{\text{days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{\text{rec}} (\text{years}) \times ET_{\text{rec}} \left(\frac{\text{hour}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{ext-1cm}} \times ACF_{\text{ext-1cm}}$$

- Direct External Exposure to contamination 5 cm thick

$$CDI_{\text{rec-soil-5cm}} (\text{pCi-year/g}) = C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times EF_{\text{rec}} \left(\frac{\text{days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{\text{rec}} (\text{years}) \times ET_{\text{rec}} \left(\frac{\text{hour}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{ext-5cm}} \times ACF_{\text{ext-5cm}}$$

- Direct External Exposure to contamination 15 cm thick

$$CDI_{\text{rec-soil-15cm}} (\text{pCi-year/g}) = C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times EF_{\text{rec}} \left(\frac{\text{days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{\text{rec}} (\text{years}) \times ET_{\text{rec}} \left(\frac{\text{hour}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{ext-15cm}} \times ACF_{\text{ext-15cm}}$$

- Direct External Exposure to surface contamination

$$CDI_{\text{rec-soil-gp}} (\text{pCi-year/g}) = C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times EF_{\text{rec}} \left(\frac{\text{days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{\text{rec}} (\text{years}) \times ET_{\text{rec}} \left(\frac{\text{hour}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{ext-gp}} \times ACF_{\text{ext-gp}}$$

Definitions of the input variables are in [Table 1](#).

4.6.3 Recreator Air

This receptor spends time involved in recreational activities. There are no default PRGs for this scenario, only site-specific.

Graphical Representation



PRG Equations

The recreator ambient air land use equation, presented here, contains the following exposure routes:

- inhalation

$$PRG_{\text{rec-air-inh}} \left(\text{pCi/m}^3 \right) = \frac{TR}{SF_i \left(\frac{\text{risk}}{\text{pCi}} \right) \times IFA_{\text{rec-adj}} \left(\text{m}^3 \right)}$$

where:

$$IFA_{\text{rec-adj}} \left(\text{m}^3 \right) = \left(\left(EF_{\text{rec-c}} \left(\frac{\text{days}}{\text{year}} \right) \times ED_{\text{rec-c}} \left(\text{years} \right) \times ET_{\text{rec-c}} \left(\frac{\text{hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{\text{rec-c}} \left(\frac{10 \text{ m}^3}{\text{day}} \right) \right) + \left(EF_{\text{rec-a}} \left(\frac{\text{days}}{\text{year}} \right) \times ED_{\text{rec-a}} \left(\text{years} \right) \times ET_{\text{rec-a}} \left(\frac{\text{hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{\text{rec-a}} \left(\frac{20 \text{ m}^3}{\text{day}} \right) \right) \right)$$

- external exposure to ionizing radiation

$$PRG_{\text{rec-air-sub}} \left(\text{pCi/m}^3 \right) = \frac{TR}{SF_{\text{sub}} \left(\frac{\text{risk/year}}{\text{pCi/m}^3} \right) \times EF_{\text{rec}} \left(\frac{\text{days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{\text{rec}} \left(\text{years} \right) \times ET_{\text{rec}} \left(\frac{\text{hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a \left(1.0 \right)}$$

- total

$$PRG_{\text{rec-air-tot}} \left(\text{pCi/m}^3 \right) = \frac{1}{\frac{1}{PRG_{\text{rec-air-inh}}} + \frac{1}{PRG_{\text{rec-air-sub}}}}$$

In situations where the contaminant in the air is not being replenished (e.g., an accidental one-time air release from a factory), decay should be used. In situations where the contaminant in the air has a continual source (e.g., indoor radon from radium in the soil or an operating factory or landfill cap), the equations without decay should be used. The decay function, found in section 4.10.7, can be multiplied by the ambient air equations above to acquire ambient air PRGs with decay.

Definitions of the input variables are in [Table 1](#).

CDI Equations

The recreator ambient air land use equation, presented here, contains the following exposure routes:

- inhalation

$$CDI_{\text{rec-air-inh}} (\text{pCi}) = C_{\text{air}} \left(\frac{\text{pCi}}{\text{m}^3} \right) \times IFA_{\text{rec-adj}} (\text{m}^3)$$

where:

$$IFA_{\text{rec-adj}} (\text{m}^3) = \left[\left(EF_{\text{rec-c}} \left(\frac{\text{days}}{\text{year}} \right) \times ED_{\text{rec-c}} (\text{years}) \times ET_{\text{rec-c}} \left(\frac{\text{hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{\text{rec-c}} \left(\frac{10 \text{ m}^3}{\text{day}} \right) \right) + \left(EF_{\text{rec-a}} \left(\frac{\text{days}}{\text{year}} \right) \times ED_{\text{rec-a}} (\text{years}) \times ET_{\text{rec-a}} \left(\frac{\text{hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{\text{rec-a}} \left(\frac{20 \text{ m}^3}{\text{day}} \right) \right) \right]$$

- external exposure to ionizing radiation

$$CDI_{\text{rec-air-sub}} (\text{pCi-year/m}^3) = C_{\text{air}} \left(\frac{\text{pCi}}{\text{m}^3} \right) \times EF_{\text{rec}} \left(\frac{\text{days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{\text{rec}} (\text{years}) \times ET_{\text{rec}} \left(\frac{\text{hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)$$

Definitions of the input variables are in [Table 1](#).

4.6.4 Recreator Consumption of Fowl and Land Game

This receptor spends time involved in recreational hunting of waterfowl and land game. There are no default PRGs for this scenario, only site-specific.

Graphical Representation



PRG Equations

The consumption of fowl and game equations, presented here, contains the following exposure routes:

- consumption of fowl - direct

$$PRG_{\text{rec-fowl-ing}} (\text{pCi/g}) = \frac{TR}{SF_f \left(\frac{\text{risk}}{\text{pCi}} \right) \times EF_{\text{rec}} \left(\frac{\text{days}}{\text{year}} \right) \times ED_{\text{rec}} (\text{years}) \times IRGF_{\text{rec}} \left(\frac{\text{g}}{\text{day}} \right) \times CF_{\text{fowl}} (1)}$$

- consumption of land game - direct

$$PRG_{\text{rec-game-ing}} (\text{pCi/g}) = \frac{TR}{SF_f \left(\frac{\text{risk}}{\text{pCi}} \right) \times EF_{\text{rec}} \left(\frac{\text{days}}{\text{year}} \right) \times ED_{\text{rec}} (\text{years}) \times IRGL_{\text{rec}} \left(\frac{\text{g}}{\text{day}} \right) \times CF_{\text{game}} (1)}$$

Definitions of the input variables are in [Table 1](#).

CDI Equations

The consumption of fowl and game equations, presented here, contains the following exposure routes:

- consumption of fowl - direct

$$CDI_{\text{rec-fowl-ing}} (\text{pCi}) = C_{\text{fowl}} \left(\frac{\text{pCi}}{\text{g}} \right) \times EF_{\text{rec}} \left(\frac{\text{days}}{\text{year}} \right) \times ED_{\text{rec}} (\text{years}) \times IRGF_{\text{rec}} \left(\frac{\text{g}}{\text{day}} \right) \times CF_{\text{rec-fowl}} (1)$$

- consumption of land game - direct

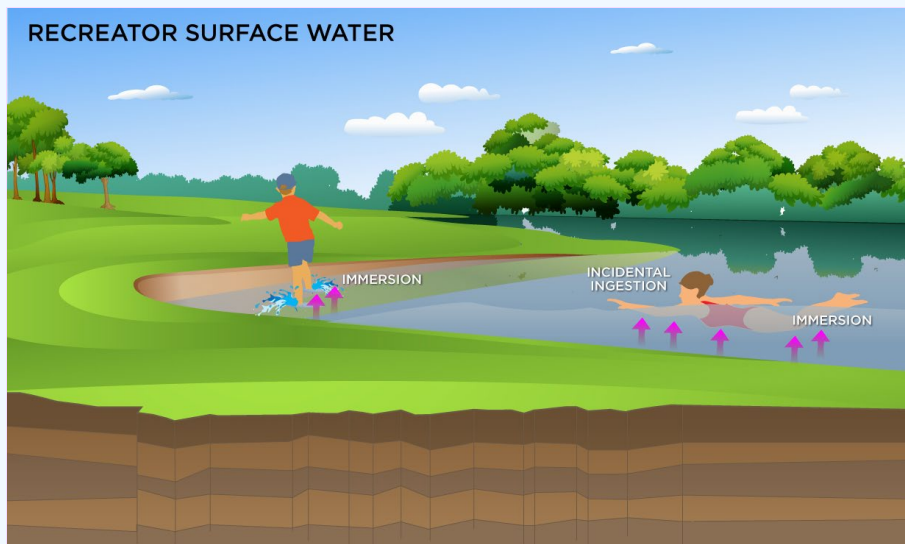
$$CDI_{\text{rec-game-ing}} (\text{pCi}) = C_{\text{game}} \left(\frac{\text{pCi}}{\text{g}} \right) \times EF_{\text{rec}} \left(\frac{\text{days}}{\text{year}} \right) \times ED_{\text{rec}} (\text{years}) \times IRGL_{\text{rec}} \left(\frac{\text{g}}{\text{day}} \right) \times CF_{\text{rec-game}} (1)$$

Definitions of the input variables are in [Table 1](#).

4.6.5 Recreator Surface Water

This receptor is exposed to radionuclides that are present in surface water. Ingestion of water and immersion in water are appropriate pathways for all radionuclides. Inhalation is not considered due to mixing with outdoor air. There are no default PRGs for this scenario, only site-specific.

Graphical Representation



PRG Equations

- ingestion of surface water

$$PRG_{\text{rec-water-ing}} (\text{pCi/L}) = \frac{TR}{SF_w \left(\frac{\text{risk}}{\text{pCi}} \right) \times IFW_{\text{rec-adj}} (L)}$$

where:

$$IFW_{\text{rec-adj}} (L) = \left(\left(EF_{\text{rec-c}} \left(\frac{\text{days}}{\text{year}} \right) \times ED_{\text{rec-c}} (\text{years}) \times ET_{\text{event-rec-c}} \left(\frac{\text{hours}}{\text{event}} \right) \times EV_{\text{rec-c}} \left(\frac{\text{events}}{\text{day}} \right) \times IRW_{\text{rec-c}} \left(\frac{0.12 \text{ L}}{\text{hour}} \right) \right) + \left(EF_{\text{rec-a}} \left(\frac{\text{days}}{\text{year}} \right) \times ED_{\text{rec-a}} (\text{years}) \times ET_{\text{event-rec-a}} \left(\frac{\text{hours}}{\text{event}} \right) \times EV_{\text{rec-a}} \left(\frac{\text{events}}{\text{day}} \right) \times IRW_{\text{rec-a}} \left(\frac{0.11 \text{ L}}{\text{hour}} \right) \right) \right)$$

- immersion

$$PRG_{\text{rec-water-imm}} (\text{pCi/L}) = \frac{TR}{SF_{\text{imm}} \left(\frac{\text{risk/year}}{\text{pCi/L}} \right) \times \left(\frac{1 \text{ years}}{8760 \text{ hours}} \right) \times DFA_{\text{rec-adj}} (\text{hours})}$$

where:

$$DFA_{\text{rec-adj}} (\text{hours}) = \left(\left(EF_{\text{rec-c}} \left(\frac{\text{days}}{\text{year}} \right) \times ED_{\text{rec-c}} (\text{years}) \times EV_{\text{rec-c}} \left(\frac{\text{events}}{\text{day}} \right) \times ET_{\text{event-rec-c}} \left(\frac{\text{hours}}{\text{event}} \right) \right) + \left(EF_{\text{rec-a}} \left(\frac{\text{days}}{\text{year}} \right) \times ED_{\text{rec-a}} (\text{years}) \times EV_{\text{rec-a}} \left(\frac{\text{events}}{\text{day}} \right) \times ET_{\text{event-rec-a}} \left(\frac{\text{hours}}{\text{event}} \right) \right) \right)$$

- consumption of land game - combined water and biota .

$$PRG_{\text{rec-water-ing-game}} (\text{pCi/L}) = \frac{PRG_{\text{rec-game-ing}} (\text{pCi/g})}{TF_{\text{game}} \left(\frac{\text{day}}{\text{kg}} \right) \times Q_{\text{wgame}} \left(\frac{\text{L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right)}$$

The transfer factor for game is the same transfer factor used for beef.

- consumption of fowl - combined water and biota

$$PRG_{\text{rec-water-ing-fowl}} (\text{pCi/L}) = \frac{PRG_{\text{rec-fowl-ing}} (\text{pCi/g})}{TF_{\text{fowl}} \left(\frac{\text{day}}{\text{kg}} \right) \times Q_{\text{w-fowl}} \left(\frac{\text{L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right)}$$

The transfer factor for fowl is the same transfer factor used for poultry.

- total

$$PRG_{\text{rec-water-tot}} (\text{pCi/L}) = \frac{1}{PRG_{\text{rec-water-ing}}} + \frac{1}{PRG_{\text{rec-water-imm}}} + \frac{1}{PRG_{\text{rec-water-ing-game}}} + \frac{1}{PRG_{\text{rec-water-ing-fowl}}}$$

Definitions of the input variables are in [Table 1](#).

CDI Equations

- ingestion of surface water

$$CDI_{\text{rec-water-ing}} (\text{pCi}) = C_{\text{s-water}} \left(\frac{\text{pCi}}{\text{L}} \right) \times IFW_{\text{rec-adj}} (\text{L})$$

where:

$$IFW_{\text{rec-adj}} (\text{L}) = \left(\left(EF_{\text{rec-c}} \left(\frac{\text{days}}{\text{year}} \right) \times ED_{\text{rec-c}} (\text{years}) \times ET_{\text{event-rec-c}} \left(\frac{\text{hours}}{\text{event}} \right) \times EV_{\text{rec-c}} \left(\frac{\text{events}}{\text{day}} \right) \times IRW_{\text{rec-c}} \left(\frac{0.12 \text{ L}}{\text{hour}} \right) \right) + \left(EF_{\text{rec-a}} \left(\frac{\text{days}}{\text{year}} \right) \times ED_{\text{rec-a}} (\text{years}) \times ET_{\text{event-rec-a}} \left(\frac{\text{hours}}{\text{event}} \right) \times EV_{\text{rec-a}} \left(\frac{\text{events}}{\text{day}} \right) \times IRW_{\text{rec-a}} \left(\frac{0.11 \text{ L}}{\text{hour}} \right) \right) \right)$$

- immersion

$$CDI_{\text{rec-water-imm}} (\text{pCi-year/L}) = C_{\text{s-water}} \left(\frac{\text{pCi}}{\text{L}} \right) \times \left(\frac{1 \text{ year}}{8760 \text{ hours}} \right) \times DFA_{\text{rec-adj}} (\text{hours})$$

where:

$$DFA_{\text{rec-adj}} (\text{hours}) = \left(\left(EF_{\text{rec-c}} \left(\frac{\text{days}}{\text{year}} \right) \times ED_{\text{rec-c}} (\text{years}) \times EV_{\text{rec-c}} \left(\frac{\text{events}}{\text{day}} \right) \times ET_{\text{event-rec-c}} \left(\frac{\text{hours}}{\text{event}} \right) \right) + \left(EF_{\text{rec-a}} \left(\frac{\text{days}}{\text{year}} \right) \times ED_{\text{rec-a}} (\text{years}) \times EV_{\text{rec-a}} \left(\frac{\text{events}}{\text{day}} \right) \times ET_{\text{event-rec-a}} \left(\frac{\text{hours}}{\text{event}} \right) \right) \right)$$

- consumption of game - combined water and biota

$$CDI_{\text{rec-water-ing-game}} (\text{pCi}) = C_{\text{s-water}} \left(\frac{\text{pCi}}{\text{L}} \right) \times TF_{\text{game}} \left(\frac{\text{day}}{\text{kg}} \right) \times Q_{\text{w-game}} \left(\frac{\text{L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \times EF_{\text{rec}} \left(\frac{\text{days}}{\text{year}} \right) \times ED_{\text{rec}} (\text{years}) \times IRGL_{\text{game}} \left(\frac{\text{g}}{\text{day}} \right) \times CF_{\text{rec-game}} (1)$$

The transfer factor for game is the same transfer factor used for beef.

- consumption of fowl - combined water and biota

$$CDI_{\text{rec-water-ing-fowl}} (\text{pCi}) = C_{\text{s-water}} \left(\frac{\text{pCi}}{\text{L}} \right) \times TF_{\text{fowl}} \left(\frac{\text{day}}{\text{kg}} \right) \times Q_{\text{w-fowl}} \left(\frac{\text{L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \times EF_{\text{rec}} \left(\frac{\text{days}}{\text{year}} \right) \times ED_{\text{rec}} (\text{years}) \times IRGF_{\text{fowl}} \left(\frac{\text{g}}{\text{day}} \right) \times CF_{\text{rec-fowl}} (1)$$

The transfer factor for fowl is the same transfer factor used for poultry.

Definitions of the input variables are in [Table 1](#).

4.7 Consumption of Fish

The fish PRG represents the concentration in the fish that can be consumed. This is unlike the farmer scenario, where the PRG is calculated for soil or water levels protective of fish consumption. Instead, this PRG is fin fish tissue. Further, the intake rate is not age-adjusted like the farmer scenario.

Graphical Representation



PRG Equation

The consumption of fish equation, presented here, contains the following exposure route:

- consumption of fish.

$$PRG_{\text{res-fish-ing}} (\text{pCi/g}) = \frac{TR}{SF_f \left(\frac{\text{risk}}{\text{pCi}} \right) \times EF_{\text{res}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{res}} (26 \text{ years}) \times IRFI_{\text{res-a}} \left(\frac{54,000 \text{ mg}}{\text{day}} \right) \times \left(\frac{10^{-3} \text{ g}}{1 \text{ mg}} \right) \times CF_{\text{res-fish}} (1)}$$

Note: the consumption rate for fish is not age-adjusted for this land use. Also the PRG calculated for fish is not for soil, like for the farmer land uses, but is for fin fish tissue.

Definitions of the input variables are in [Table 1](#).

CDI Equation

The consumption of fish equation, presented here, contains the following exposure route:

- consumption of fish.

$$CDI_{\text{res-fish-ing}} (\text{pCi}) = C_{\text{fish}} \left(\frac{\text{pCi}}{\text{g}} \right) \times EF_{\text{res}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{res}} (26 \text{ years}) \times IRFI_{\text{res-a}} \left(\frac{54,000 \text{ mg}}{\text{day}} \right) \times \left(\frac{10^{-3} \text{ g}}{1 \text{ mg}} \right) \times CF_{\text{res-fish}} (1)$$

Note: the consumption rate for fish is not age-adjusted for this land use. Also the CDI calculated for fish is not for soil, like for the farmer land uses, but is for fin fish tissue.

Definitions of the input variables are in [Table 1](#).

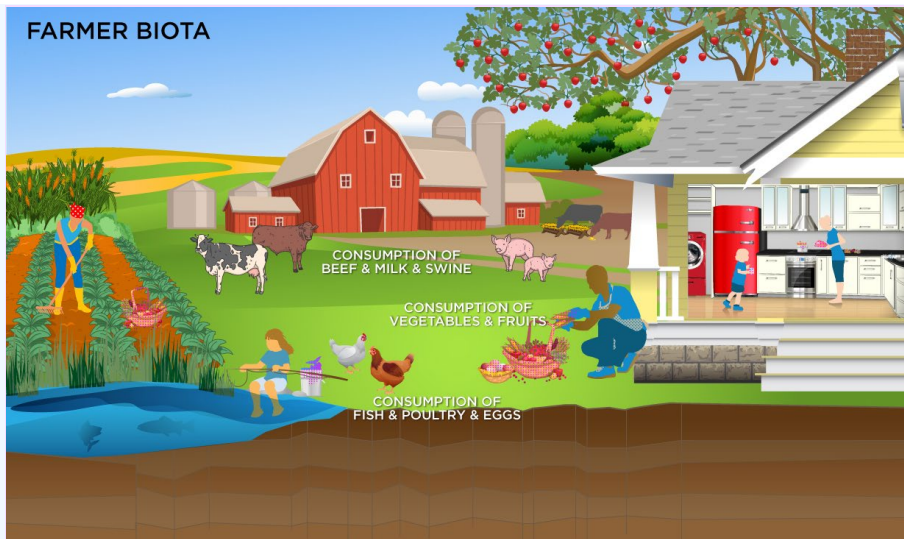
4.8 Farmer

4.8.1 Farmer Direct Consumption of Agricultural Products

The farmer scenario should be considered an extension of the resident scenario and evaluate consumption of farm products for a subsistence farmer. Like the resident, the farmer assumes the receptor will be exposed via the consumption of home grown produce (100% of fruit and vegetables are from the farm). In addition to produce, 100% of consumption of the following are also considered to be from the farm: beef, dairy, fin fish, shellfish, swine, egg, and poultry. All feed (100%) for farm products is considered to have been grown on contaminated portions of the site. For these farm products, risk-based PRGs are provided for the farm product itself (produce, beef, dairy, etc.). Also like the resident, age-adjusted intake equations were developed for all of the consumption equations to account for changes in intake as the receptor ages.

Graphical Representation

Agricultural Biota, Soil, and Water Graphic and Supporting Text



PRG Equations

- consumption of fruits and vegetables. Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 9 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-grown produce.

$$PRG_{\text{far-produce-ing tot}} (\text{pCi/g}) = \frac{1}{\left(\sum_{i=1}^n \frac{1}{PRG_{\text{far-produce-ing}} (\text{pCi/g})_i} \right)}$$

where:

n = total number of produce items included

and:

$$PRG_{\text{far-produce-ing}} (\text{pCi/g}) = \frac{TR}{SF_f \left(\frac{\text{risk}}{\text{pCi}} \right) \times IF_{\text{far-adj}} (\text{g}) \times CF_{\text{far-produce}} (\text{l})}$$

where:

$$IF_{\text{far-adj}} (\text{g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IR_{\text{far-c}} \left(\frac{\text{g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IR_{\text{far-a}} \left(\frac{\text{g}}{\text{day}} \right) \right) \right)$$

- consumption of poultry. Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced poultry.

$$PRG_{\text{far-poultry-ing}} (\text{pCi/g}) = \frac{TR}{SF_f \left(\frac{\text{risk}}{\text{pCi}} \right) \times IFP_{\text{far-adj}} (2,190,930 \text{ g}) \times CF_{\text{far-poultry}} (\text{l})}$$

where:

$$IFP_{\text{far-adj}} (2,190,930 \text{ g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IRP_{\text{far-c}} \left(\frac{48.8 \text{ g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IRP_{\text{far-a}} \left(\frac{175.5 \text{ g}}{\text{day}} \right) \right) \right)$$

- consumption of eggs. Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced eggs.

$$PRG_{\text{far-egg-ing}} (\text{pCi/g}) = \frac{TR}{SF_f \left(\frac{\text{risk}}{\text{pCi}} \right) \times IFE_{\text{far-adj}} (1,210,580 \text{ g}) \times CF_{\text{far-egg}} (\text{l})}$$

where:

$$IFE_{\text{far-adj}} (1,210,580 \text{ g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IRE_{\text{far-c}} \left(\frac{25.1 \text{ g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IRE_{\text{far-a}} \left(\frac{97.3 \text{ g}}{\text{day}} \right) \right) \right)$$

- consumption of beef. Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced beef.

$$PRG_{\text{far-beef-ing}} (\text{pCi/g}) = \frac{TR}{SF_f \left(\frac{\text{risk}}{\text{pCi}} \right) \times IFB_{\text{far-adj}} (3,349,850 \text{ g}) \times CF_{\text{far-beef}} (1)}$$

where:

$$IFB_{\text{far-adj}} (3,349,850 \text{ g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IRB_{\text{far-c}} \left(\frac{64.6 \text{ g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IRB_{\text{far-a}} \left(\frac{270.1 \text{ g}}{\text{day}} \right) \right) \right)$$

- **consumption of dairy.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced dairy.

$$PRG_{\text{far-dairy-ing}} (\text{pCi/g}) = \frac{TR}{SF_f \left(\frac{\text{risk}}{\text{pCi}} \right) \times IFD_{\text{far-adj}} (19,456,640 \text{ g}) \times CF_{\text{far-dairy}} (1)}$$

where:

$$IFD_{\text{far-adj}} (19,456,640 \text{ g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IRD_{\text{far-c}} \left(\frac{1116.4 \text{ g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IRD_{\text{far-a}} \left(\frac{1438.0 \text{ g}}{\text{day}} \right) \right) \right)$$

- **consumption of swine.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced swine.

$$PRG_{\text{far-swine-ing}} (\text{pCi/g}) = \frac{TR}{SF_f \left(\frac{\text{risk}}{\text{pCi}} \right) \times IFSW_{\text{far-adj}} (1,865,710 \text{ g}) \times CF_{\text{far-swine}} (1)}$$

where:

$$IFSW_{\text{far-adj}} (1,865,710 \text{ g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IRSW_{\text{far-c}} \left(\frac{32.2 \text{ g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IRSW_{\text{far-a}} \left(\frac{151.1 \text{ g}}{\text{day}} \right) \right) \right)$$

- **consumption of fin fish.** Chapters 10 and 13 of the 2011 [Exposure Factors Handbook](#) were used to derive the intakes for home-caught fin fish.

$$PRG_{\text{far-finfish-ing}} (\text{pCi/g}) = \frac{TR}{SF_f \left(\frac{\text{risk}}{\text{pCi}} \right) \times IFFI_{\text{far-adj}} (1,931,020 \text{ g}) \times CF_{\text{far-finfish}} (1)}$$

where:

$$IFFI_{\text{far-adj}} (1,931,020 \text{ g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IRFI_{\text{far-c}} \left(\frac{36.1 \text{ g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IRFI_{\text{far-a}} \left(\frac{155.9 \text{ g}}{\text{day}} \right) \right) \right)$$

- **consumption of shellfish.** Table 10-9 of the 2011 [Exposure Factors Handbook](#) was used to derive the intakes for home-caught shellfish.

$$PRG_{\text{far-shellfish-ing}} (\text{pCi/g}) = \frac{TR}{SF_f \left(\frac{\text{risk}}{\text{pCi}} \right) \times IFSF_{\text{far-adj}} (2,530,640 \text{ g}) \times CF_{\text{far-shellfish}} (1)}$$

where:

$$IFSF_{\text{far-adj}} (2,530,640 \text{ g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IRSF_{\text{far-c}} \left(\frac{21.3 \text{ g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IRSF_{\text{far-a}} \left(\frac{208.9 \text{ g}}{\text{day}} \right) \right) \right)$$

- **consumption of goat.**

$$PRG_{\text{far-goat-ing}}(\text{pCi/g}) = \frac{TR}{SF_f \left(\frac{\text{risk}}{\text{pCi}} \right) \times IFGO_{\text{far-adj}}(\text{g}) \times CF_{\text{far-goat}}(1)}$$

where:

$$IFGO_{\text{far-adj}}(\text{g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}}(6 \text{ years}) \times IRGO_{\text{far-c}} \left(\frac{\text{g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}}(34 \text{ years}) \times IRGO_{\text{far-a}} \left(\frac{\text{g}}{\text{day}} \right) \right) \right)$$

- consumption of goat milk.

$$PRG_{\text{far-goat-milk-ing}}(\text{pCi/g}) = \frac{TR}{SF_f \left(\frac{\text{risk}}{\text{pCi}} \right) \times IFGM_{\text{far-adj}}(\text{g}) \times CF_{\text{far-goat-milk}}(1)}$$

where:

$$IFGM_{\text{far-adj}}(\text{g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}}(6 \text{ years}) \times IRGM_{\text{far-c}} \left(\frac{\text{g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}}(34 \text{ years}) \times IRGM_{\text{far-a}} \left(\frac{\text{g}}{\text{day}} \right) \right) \right)$$

- consumption of sheep.

$$PRG_{\text{far-sheep-ing}}(\text{pCi/g}) = \frac{TR}{SF_f \left(\frac{\text{risk}}{\text{pCi}} \right) \times IFSH_{\text{far-adj}}(\text{g}) \times CF_{\text{far-sheep}}(1)}$$

where:

$$IFSH_{\text{far-adj}}(\text{g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}}(6 \text{ years}) \times IRSH_{\text{far-c}} \left(\frac{\text{g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}}(34 \text{ years}) \times IRSH_{\text{far-a}} \left(\frac{\text{g}}{\text{day}} \right) \right) \right)$$

- consumption of sheep milk.

$$PRG_{\text{far-sheep-milk-ing}}(\text{pCi/g}) = \frac{TR}{SF_f \left(\frac{\text{risk}}{\text{pCi}} \right) \times IFSM_{\text{far-adj}}(\text{g}) \times CF_{\text{far-sheep-milk}}(1)}$$

where:

$$IFSM_{\text{far-adj}}(\text{g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}}(6 \text{ years}) \times IRSM_{\text{far-c}} \left(\frac{\text{g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}}(34 \text{ years}) \times IRSM_{\text{far-a}} \left(\frac{\text{g}}{\text{day}} \right) \right) \right)$$

Definitions of the input variables are in [Table 1](#).

CDI Equations

- consumption of fruits and vegetables. Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 9 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-grown produce.

$$CDI_{\text{far-produce-ing-tot}}(\text{pCi}) = \sum_{i=1}^n CDI_{\text{far-produce-ing}}(\text{pCi})_i$$

where:

n = total number of produce items included

and:

$$CDI_{\text{far-produce-ing}}(\text{pCi}) = C_{\text{produce}} \left(\frac{\text{pCi}}{\text{g}} \right) \times IF_{\text{far-adj}}(\text{g}) \times CF_{\text{far-produce}}(1)$$

where:

$$IF_{\text{far-adj}}(\text{g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}}(6 \text{ years}) \times IR_{\text{far-c}} \left(\frac{\text{g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}}(34 \text{ years}) \times IR_{\text{far-a}} \left(\frac{\text{g}}{\text{day}} \right) \right) \right)$$

- consumption of poultry. Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced poultry.

$$CDI_{\text{far-poultry-ing}}(\text{pCi}) = C_{\text{poultry}} \left(\frac{\text{pCi}}{\text{g}} \right) \times IFP_{\text{far-adj}}(2,190,930 \text{ g}) \times CF_{\text{far-poultry}}(1)$$

where:

$$IFP_{\text{far-adj}}(2,190,930 \text{ g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}}(6 \text{ years}) \times IRP_{\text{far-c}} \left(\frac{48.8 \text{ g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}}(34 \text{ years}) \times IRP_{\text{far-a}} \left(\frac{175.5 \text{ g}}{\text{day}} \right) \right) \right)$$

- **consumption of eggs.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced eggs.

$$CDI_{\text{far-egg-ing}}(\text{pCi}) = C_{\text{egg}} \left(\frac{\text{pCi}}{\text{g}} \right) \times IFE_{\text{far-adj}}(1,210,580 \text{ g}) \times CF_{\text{far-egg}}(1)$$

where:

$$IFE_{\text{far-adj}}(1,210,580 \text{ g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}}(6 \text{ years}) \times IRE_{\text{far-c}} \left(\frac{25.1 \text{ g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}}(34 \text{ years}) \times IRE_{\text{far-a}} \left(\frac{97.3 \text{ g}}{\text{day}} \right) \right) \right)$$

- **consumption of beef.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced beef.

$$CDI_{\text{far-beef-ing}}(\text{pCi}) = C_{\text{beef}} \left(\frac{\text{pCi}}{\text{g}} \right) \times IFB_{\text{far-adj}}(3,349,850 \text{ g}) \times CF_{\text{far-beef}}(1)$$

where:

$$IFB_{\text{far-adj}}(3,349,850 \text{ g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}}(6 \text{ years}) \times IRB_{\text{far-c}} \left(\frac{64.6 \text{ g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}}(34 \text{ years}) \times IRB_{\text{far-a}} \left(\frac{270.1 \text{ g}}{\text{day}} \right) \right) \right)$$

- **consumption of dairy.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced dairy.

$$CDI_{\text{far-dairy-ing}}(\text{pCi}) = C_{\text{dairy}} \left(\frac{\text{pCi}}{\text{g}} \right) \times IFD_{\text{far-adj}}(19,456,640 \text{ g}) \times CF_{\text{far-dairy}}(1)$$

where:

$$IFD_{\text{far-adj}}(19,456,640 \text{ g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}}(6 \text{ years}) \times IRD_{\text{far-c}} \left(\frac{1116.4 \text{ g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}}(34 \text{ years}) \times IRD_{\text{far-a}} \left(\frac{1438.0 \text{ g}}{\text{day}} \right) \right) \right)$$

- **consumption of swine.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced swine.

$$CDI_{\text{far-swine-ing}}(\text{pCi}) = C_{\text{swine}} \left(\frac{\text{pCi}}{\text{g}} \right) \times IFSW_{\text{far-adj}}(1,865,710 \text{ g}) \times CF_{\text{far-swine}}(1)$$

where:

$$IFSW_{\text{far-adj}}(1,865,710 \text{ g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}}(6 \text{ years}) \times IRSW_{\text{far-c}} \left(\frac{32.2 \text{ g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}}(34 \text{ years}) \times IRSW_{\text{far-a}} \left(\frac{151.1 \text{ g}}{\text{day}} \right) \right) \right)$$

- **consumption of fin fish.** Chapters 10 and 13 of the 2011 [Exposure Factors Handbook](#) were used to derive the intakes for home-caught fin fish.

$$CDI_{\text{far-finish-ing}}(\text{pCi}) = C_{\text{finfish}} \left(\frac{\text{pCi}}{\text{g}} \right) \times IFFI_{\text{far-adj}}(1,931,020 \text{ g}) \times CF_{\text{far-finish}}(1)$$

where:

$$IFFI_{\text{far-adj}}(1,931,020 \text{ g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}}(6 \text{ years}) \times IRFI_{\text{far-c}} \left(\frac{36.1 \text{ g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}}(34 \text{ years}) \times IRFI_{\text{far-a}} \left(\frac{155.9 \text{ g}}{\text{day}} \right) \right) \right)$$

- consumption of shellfish. Table 10-9 of the 2011 [Exposure Factors Handbook](#) was used to derive the intakes for home-caught shellfish.

$$CDI_{\text{far-shellfish-ing}} (\text{pCi}) = C_{\text{shellfish}} \left(\frac{\text{pCi}}{\text{g}} \right) \times \text{IFSF}_{\text{far-adj}} (2,530,640 \text{ g}) \times CF_{\text{far-shellfish}} (1)$$

where:

$$\text{IFSF}_{\text{far-adj}} (2,530,640 \text{ g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times \text{IRSF}_{\text{far-c}} \left(\frac{21.3 \text{ g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times \text{IRSF}_{\text{far-a}} \left(\frac{208.9 \text{ g}}{\text{day}} \right) \right) \right)$$

- consumption of goat.

$$CDI_{\text{far-goat-ing}} (\text{pCi}) = C_{\text{goat}} \left(\frac{\text{pCi}}{\text{g}} \right) \times \text{IFGO}_{\text{far-adj}} (\text{g}) \times CF_{\text{far-goat}} (1)$$

where:

$$\text{IFGO}_{\text{far-adj}} (\text{g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times \text{IRGO}_{\text{far-c}} \left(\frac{\text{g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times \text{IRGO}_{\text{far-a}} \left(\frac{\text{g}}{\text{day}} \right) \right) \right)$$

- consumption of goat milk.

$$CDI_{\text{far-goat-milk-ing}} (\text{pCi}) = C_{\text{goat-milk}} \left(\frac{\text{pCi}}{\text{g}} \right) \times \text{IFGM}_{\text{far-adj}} (\text{g}) \times CF_{\text{far-goat-milk}} (1)$$

where:

$$\text{IFGM}_{\text{far-adj}} (\text{g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times \text{IRGM}_{\text{far-c}} \left(\frac{\text{g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times \text{IRGM}_{\text{far-a}} \left(\frac{\text{g}}{\text{day}} \right) \right) \right)$$

- consumption of sheep.

$$CDI_{\text{far-sheep-ing}} (\text{pCi}) = C_{\text{sheep}} \left(\frac{\text{pCi}}{\text{g}} \right) \times \text{IFSH}_{\text{far-adj}} (\text{g}) \times CF_{\text{far-sheep}} (1)$$

where:

$$\text{IFSH}_{\text{far-adj}} (\text{g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times \text{IRSH}_{\text{far-c}} \left(\frac{\text{g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times \text{IRSH}_{\text{far-a}} \left(\frac{\text{g}}{\text{day}} \right) \right) \right)$$

- consumption of sheep milk.

$$CDI_{\text{far-sheep-milk-ing}} (\text{pCi}) = C_{\text{sheep-milk}} \left(\frac{\text{pCi}}{\text{g}} \right) \times \text{IFSM}_{\text{far-adj}} (\text{g}) \times CF_{\text{far-sheep-milk}} (1)$$

where:

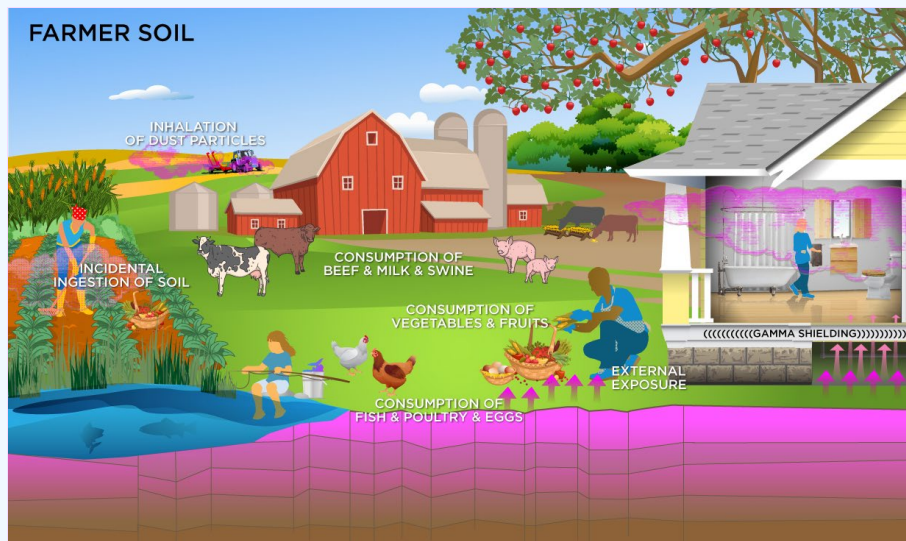
$$\text{IFSM}_{\text{far-adj}} (\text{g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times \text{IRSM}_{\text{far-c}} \left(\frac{\text{g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times \text{IRSM}_{\text{far-a}} \left(\frac{\text{g}}{\text{day}} \right) \right) \right)$$

Definitions of the input variables are in [Table 1](#).

4.8.2 Farmer Direct Exposure and Consumption of Agricultural Products - Combined Soil and Biota

The farmer scenario should be considered an extension of the resident scenario and evaluates consumption of farm products for a subsistence farmer. Like the resident, the farmer scenario assumes the receptor will be exposed via the following pathways: incidental ingestion of soil, external radiation from contaminants in soil, and inhalation of fugitive dust and consumption of home grown produce (100% of fruit and vegetables are from the farm). In addition to produce, 100% of consumption of the following are also considered to be from the farm: beef, dairy, fin fish, shellfish, swine, egg, and poultry. All feed (100%) for farm products is considered to have been grown on contaminated portions of the site. For these farm products, risk-based PRGs are provided for soil, which may contribute contaminants to the products. Also like the resident, age-adjusted intake equations were developed for all of the ingestion/consumption equations to account for changes in intake as the receptor ages.

Graphical Representation



PRG Equations

- incidental ingestion of soil,

$$PRG_{\text{far-soil-ing}} (\text{pCi/g}) = \frac{TR}{SF_s \left(\frac{\text{risk}}{\text{pCi}} \right) \times IFS_{\text{far-adj}} (1,610,000 \text{ mg}) \times \left(\frac{\text{g}}{1000 \text{ mg}} \right)}$$

where:

$$IFS_{\text{far-adj}} (1,610,000 \text{ mg}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IRS_{\text{far-c}} \left(\frac{200 \text{ mg}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IRS_{\text{far-a}} \left(\frac{100 \text{ mg}}{\text{day}} \right) \right) \right)$$

- inhalation of particulates emitted from soil,

$$PRG_{\text{far-soil-inh}} (\text{pCi/g}) = \frac{TR}{SF_i \left(\frac{\text{risk}}{\text{pCi}} \right) \times IFA_{\text{far-adj}} (259,000 \text{ m}^3) \times \frac{1}{PEF \left(\frac{\text{m}^3}{\text{kg}} \right)} \times \left(\frac{1000 \text{ g}}{\text{kg}} \right)}$$

where:

$$IFA_{\text{far-adj}} (259,000 \text{ m}^3) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times ET_{\text{far-c}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{\text{far-c}} \left(\frac{10 \text{ m}^3}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times ET_{\text{far-a}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{\text{far-a}} \left(\frac{20 \text{ m}^3}{\text{day}} \right) \right) \right)$$

- external exposure to ionizing radiation, and

$$PRG_{\text{far-soil-ext}} (\text{pCi/g}) = \frac{TR}{SF_{\text{ext-sv}} \left(\frac{\text{risk/year}}{\text{pCi/g}} \right) \times EF \left(\frac{350 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{\text{far}} (40 \text{ years}) \times ACF_{\text{ext-sv}} \times \left[\left(ET_{\text{far-o}} \left(\frac{12,168 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{o-ext-sv}} \right) + \left(ET_{\text{far-i}} \left(\frac{10,008 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{f-total}} \right) \right]}$$

- consumption of fruits and vegetables. Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 9 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-grown produce

The consumption of produce exposure route drives the PRGs lower than all the other routes. It is recommended that produce-specific transfer factors (Bv_{wet}) be used when available for a site.

Further, the default transfer factors (Bv_{wet}) from IAEA, used in these PRG calculations, are based on a composite of all soil groups. Transfer factors (Bv_{wet}) for sand, loam, clay, organic, coral sand, and other soil types that may be more suited to a particular site are also provided. The site-specific option of the calculator can be used to focus on ingestion of individual produce types. When "Site-Specific" is selected, if the user changes the "Select Isotope Info Type" to "User-provided", then a specific transfer factor may be changed.

$$PRG_{\text{far-soil-produce-ing-tot}} (\text{pCi/g}) = \frac{1}{\left(\sum_{i=1}^n \frac{1}{PRG_{\text{far-soil-produce-ing}} (\text{pCi/g})_i} \right)}$$

where:

n = total number of produce items included

and:

$$PRG_{\text{far-soil-produce-ing}} (\text{pCi/g}) = \frac{PRG_{\text{far-produce-ing}} (\text{pCi/g})}{(R_{\text{upv}} + R_{\text{es}})}$$

where:

$$R_{\text{upv}} = Bv_{\text{wet}} \left(\frac{\text{pCi / g-fresh plant}}{\text{pCi / g-dry soil}} \right); R_{\text{es}} = MLF_{\text{produce}} \left(\frac{\text{g-dry soil}}{\text{g-fresh plant}} \right)$$

where:

$$PRG_{\text{far-produce-ing-tot}} (\text{pCi/g}) = \frac{1}{\left(\sum_{i=1}^n \frac{1}{PRG_{\text{far-produce-ing}} (\text{pCi/g})_i} \right)}$$

where:

n = total number of produce items included

and:

$$PRG_{\text{far-produce-ing}} (\text{pCi/g}) = \frac{TR}{SF_f \left(\frac{\text{risk}}{\text{pCi}} \right) \times IF_{\text{far-adj}} (\text{g}) \times CF_{\text{far-produce}} (t)}$$

where:

$$IF_{\text{far-adj}} (\text{g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IR_{\text{far-c}} \left(\frac{\text{g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IR_{\text{far-a}} \left(\frac{\text{g}}{\text{day}} \right) \right) \right)$$

- **consumption of poultry.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced poultry.

$$PRG_{\text{far-soil-poultry-ing}} (\text{pCi/g}) = \frac{PRG_{\text{far-poultry-ing}} (\text{pCi/g})}{TF_{\text{poultry}} \left(\frac{\text{day}}{\text{kg}} \right) \times \left[\left(Q_{\text{p-poultry}} \left(\frac{0.2 \text{ kg}}{\text{day}} \right) \times f_{\text{p-poultry}} (t) \times f_{\text{s-poultry}} (t) \times (R_{\text{upv}} + R_{\text{es}}) \right) + \left(Q_{\text{s-poultry}} \left(\frac{0.022 \text{ kg}}{\text{day}} \right) \times f_{\text{p-poultry}} (t) \right) \right]}$$

where:

$$R_{\text{upv}} = Bv_{\text{dry}} \left(\frac{\text{pCi / g-dry plant}}{\text{pCi / g-dry soil}} \right); R_{\text{es}} = MLF_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{\text{g-dry plant}} \right)$$

- **consumption of eggs.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced eggs.

$$PRG_{\text{far-soil-egg-ing}} (\text{pCi/g}) = \frac{PRG_{\text{far-egg-ing}} (\text{pCi/g})}{TF_{\text{egg}} \left(\frac{\text{day}}{\text{kg}} \right) \times \left[\left(Q_{\text{p-poultry}} \left(\frac{0.2 \text{ kg}}{\text{day}} \right) \times f_{\text{p-poultry}} (t) \times f_{\text{s-poultry}} (t) \times (R_{\text{upv}} + R_{\text{es}}) \right) + \left(Q_{\text{s-poultry}} \left(\frac{0.022 \text{ kg}}{\text{day}} \right) \times f_{\text{p-poultry}} (t) \right) \right]}$$

where:

$$R_{\text{upv}} = Bv_{\text{dry}} \left(\frac{\text{pCi / g-dry plant}}{\text{pCi / g-dry soil}} \right); R_{\text{es}} = MLF_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{\text{g-dry plant}} \right)$$

- **consumption of beef.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced beef.

$$PRG_{\text{far-soil-beef-ing}} (\text{pCi/g}) = \frac{PRG_{\text{far-beef-ing}} (\text{pCi/g})}{TF_{\text{beef}} \left(\frac{\text{day}}{\text{kg}} \right) \times \left[\left(Q_{\text{p-beef}} \left(\frac{11.77 \text{ kg}}{\text{day}} \right) \times f_{\text{p-beef}} (t) \times f_{\text{s-beef}} (t) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-beef}} \left(\frac{0.5 \text{ kg}}{\text{day}} \right) \times f_{\text{p-beef}} (t) \right) \right]}$$

where:

$$R_{\text{upp}} = Bv_{\text{dry}} \left(\frac{\text{pCi/g-dry plant}}{\text{pCi/g-dry soil}} \right); R_{\text{es}} = \text{MLF}_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{\text{g-dry plant}} \right)$$

- **consumption of dairy.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced dairy.

$$PRG_{\text{far-soil-dairy-ing}} (\text{pCi/g}) = \frac{PRG_{\text{far-dairy-ing}} (\text{pCi/g})}{TF_{\text{dairy}} \left(\frac{\text{day}}{\text{L milk}} \right) \times P_m \left(\frac{1.03 \text{ kg}}{\text{L milk}} \right)^{-1} \times \left[\left(Q_{\text{p-dairy}} \left(\frac{20.3 \text{ kg}}{\text{day}} \right) \times f_{\text{p-dairy}} (t) \times f_{\text{s-dairy}} (t) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-dairy}} \left(\frac{0.4 \text{ kg}}{\text{day}} \right) \times f_{\text{p-dairy}} (t) \right) \right]}$$

where:

$$R_{\text{upp}} = Bv_{\text{dry}} \left(\frac{\text{pCi/g-dry plant}}{\text{pCi/g-dry soil}} \right); R_{\text{es}} = \text{MLF}_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{\text{g-dry plant}} \right)$$

- **consumption of swine.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced swine.

$$PRG_{\text{far-soil-swine-ing}} (\text{pCi/g}) = \frac{PRG_{\text{far-swine-ing}} (\text{pCi/g})}{TF_{\text{swine}} \left(\frac{\text{day}}{\text{kg}} \right) \times \left[\left(Q_{\text{p-swine}} \left(\frac{4.7 \text{ kg}}{\text{day}} \right) \times f_{\text{p-swine}} (t) \times f_{\text{s-swine}} (t) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-swine}} \left(\frac{0.37 \text{ kg}}{\text{day}} \right) \times f_{\text{p-swine}} (t) \right) \right]}$$

where:

$$R_{\text{upp}} = Bv_{\text{dry}} \left(\frac{\text{pCi/g-dry plant}}{\text{pCi/g-dry soil}} \right); R_{\text{es}} = \text{MLF}_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{\text{g-dry plant}} \right)$$

- **consumption of fin fish.** Chapters 10 and 13 of the 2011 [Exposure Factors Handbook](#) were used to derive the intakes for home-caught fin fish.

$$PRG_{\text{far-soil-finish-ing}} (\text{pCi/g}) = \frac{PRG_{\text{far-finish-ing}} (\text{pCi/g}) \times Kd \left(\frac{\text{L}}{\text{kg}} \right)}{\text{BCF} \left(\frac{\text{L}}{\text{kg}} \right)}$$

- **consumption of shellfish.** Table 10-9 of the 2011 [Exposure Factors Handbook](#) was used to derive the intakes for home-caught shellfish.

$$PRG_{\text{far-soil-shellfish-ing}} (\text{pCi/g}) = \frac{PRG_{\text{far-shellfish-ing}} (\text{pCi/g}) \times Kd \left(\frac{\text{L}}{\text{kg}} \right)}{\text{BCF} \left(\frac{\text{L}}{\text{kg}} \right)}$$

- **total**

$$PRG_{\text{far-soil-tot}} (\text{pCi/g}) = \frac{1}{\frac{PRG_{\text{far-soil-ing}}}{1} + \frac{PRG_{\text{far-soil-inh}}}{1} + \frac{PRG_{\text{far-soil-ext}}}{1} + \frac{PRG_{\text{far-soil-produce-ing-tot}}}{1} + \frac{PRG_{\text{far-soil-egg-ing}}}{1} + \frac{PRG_{\text{far-soil-poultry-ing}}}{1} + \frac{PRG_{\text{far-soil-finish-ing}}}{1} + \frac{PRG_{\text{far-soil-shellfish-ing}}}{1} + \frac{PRG_{\text{far-soil-beef-ing}}}{1} + \frac{PRG_{\text{far-soil-dairy-ing}}}{1} + \frac{PRG_{\text{far-soil-swine-ing}}}{1}}$$

A number of studies have shown that inadvertent ingestion of soil is common among children 6 years old and younger (Calabrese et al. 1989, Davis et al. 1990, Van Wijnen et al. 1990). Therefore, the dose method uses an age-adjusted soil ingestion factor that takes into account the difference in daily soil ingestion rates and exposure duration for children from 1 to 6 years old and others from 7 to 40 years old. This health-protective approach is chosen to take into account the higher daily rates of soil ingestion in children as well as the longer duration of exposure that is anticipated for a long-term resident. For more on this method, see [RAGS Part B](#).

Age-adjusted intake factors are also used for inhalation of particulates emitted from soil and consumption of biota. These equations are also presented in the above equations.

The following consumption routes are provided in site-specific mode only and require the user to

enter their own data, as the tool only provides a transfer factor.

- consumption of goat.

$$PRG_{\text{far-soil-goat-ing}} (\text{pCi/g}) = \frac{PRG_{\text{far-goat-ing}} (\text{pCi/g})}{TF_{\text{goat}} \left(\frac{\text{day}}{\text{kg}} \right) \times \left[\left(Q_{\text{p-goat}} \left(\frac{1.27 \text{ kg}}{\text{day}} \right) \times f_{\text{p-goat}} (1) \times f_{\text{s-goat}} (1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-goat}} \left(\frac{0.23 \text{ kg}}{\text{day}} \right) \times f_{\text{p-goat}} (1) \right) \right]}$$

where:

$$R_{\text{upp}} = Bv_{\text{dry}} \left(\frac{\text{pCi} / \text{g-dry plant}}{\text{pCi} / \text{g-dry soil}} \right); R_{\text{es}} = MLF_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{\text{g-dry plant}} \right)$$

- consumption of goat milk.

$$PRG_{\text{far-soil-goat-milk-ing}} (\text{pCi/g}) = \frac{PRG_{\text{far-goat-milk-ing}} (\text{pCi/g})}{TF_{\text{goat-milk}} \left(\frac{\text{day}}{\text{L milk}} \right) \times \rho_m \left(\frac{1.03 \text{ kg}}{\text{L milk}} \right)^{-1} \times \left[\left(Q_{\text{p-goat-milk}} \left(\frac{1.59 \text{ kg}}{\text{day}} \right) \times f_{\text{p-goat-milk}} (1) \times f_{\text{s-goat-milk}} (1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-goat-milk}} \left(\frac{0.29 \text{ kg}}{\text{day}} \right) \times f_{\text{p-goat-milk}} (1) \right) \right]}$$

where:

$$R_{\text{upp}} = Bv_{\text{dry}} \left(\frac{\text{pCi} / \text{g-dry plant}}{\text{pCi} / \text{g-dry soil}} \right); R_{\text{es}} = MLF_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{\text{g-dry plant}} \right)$$

- consumption of sheep.

$$PRG_{\text{far-soil-sheep-ing}} (\text{pCi/g}) = \frac{PRG_{\text{far-sheep-ing}} (\text{pCi/g})}{TF_{\text{sheep}} \left(\frac{\text{day}}{\text{kg}} \right) \times \left[\left(Q_{\text{p-sheep}} \left(\frac{1.75 \text{ kg}}{\text{day}} \right) \times f_{\text{p-sheep}} (1) \times f_{\text{s-sheep}} (1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-sheep}} \left(\frac{0.32 \text{ kg}}{\text{day}} \right) \times f_{\text{p-sheep}} (1) \right) \right]}$$

where:

$$R_{\text{upp}} = Bv_{\text{dry}} \left(\frac{\text{pCi} / \text{g-dry plant}}{\text{pCi} / \text{g-dry soil}} \right); R_{\text{es}} = MLF_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{\text{g-dry plant}} \right)$$

- consumption of sheep milk.

$$PRG_{\text{far-soil-sheep-milk-ing}} (\text{pCi/g}) = \frac{PRG_{\text{far-sheep-milk-ing}} (\text{pCi/g})}{TF_{\text{sheep-milk}} \left(\frac{\text{day}}{\text{L milk}} \right) \times \rho_m \left(\frac{1.03 \text{ kg}}{\text{L milk}} \right)^{-1} \times \left[\left(Q_{\text{p-sheep-milk}} \left(\frac{3.15 \text{ kg}}{\text{day}} \right) \times f_{\text{p-sheep-milk}} (1) \times f_{\text{s-sheep-milk}} (1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-sheep-milk}} \left(\frac{0.57 \text{ kg}}{\text{day}} \right) \times f_{\text{p-sheep-milk}} (1) \right) \right]}$$

where:

$$R_{\text{upp}} = Bv_{\text{dry}} \left(\frac{\text{pCi} / \text{g-dry plant}}{\text{pCi} / \text{g-dry soil}} \right); R_{\text{es}} = MLF_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{\text{g-dry plant}} \right)$$

Definitions of the input variables are in [Table 1](#).

CDI Equations

- incidental ingestion of soil,

$$CDI_{\text{far-soil-ing}} (\text{pCi}) = C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times IFS_{\text{far-adj}} (1,610,000 \text{ mg}) \times \left(\frac{\text{g}}{1000 \text{ mg}} \right)$$

where:

$$IFS_{\text{far-adj}} (1,610,000 \text{ mg}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IRS_{\text{far-c}} \left(\frac{200 \text{ mg}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IRS_{\text{far-a}} \left(\frac{100 \text{ mg}}{\text{day}} \right) \right) \right)$$

- inhalation of particulates emitted from soil,

$$CDI_{\text{far-soil-inh}} (\text{pCi}) = C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times IFA_{\text{far-adj}} (259,000 \text{ m}^3) \times \frac{1}{PEF} \left(\frac{\text{m}^3}{\text{kg}} \right) \times \left(\frac{1000 \text{ g}}{\text{kg}} \right)$$

where:

$$IFA_{\text{far-adj}} (259,000 \text{ m}^3) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times ET_{\text{far-c}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{\text{far-c}} \left(\frac{10 \text{ m}^3}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times ET_{\text{far-a}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{\text{far-a}} \left(\frac{20 \text{ m}^3}{\text{day}} \right) \right) \right)$$

- external exposure to ionizing radiation, and

$$CDI_{\text{far-soil-ext}} (\text{pCi-year/g}) = \left[C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times EF_{\text{far}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{\text{far}} (40 \text{ years}) \times AC_{\text{ext-sw}} \times \left[\left(ET_{\text{far-o}} \left(\frac{12,168 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{ext-sw}} (1.0) \right) + \left(ET_{\text{far-i}} \left(\frac{10,008 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_{\text{i-total}} \right) \right] \right]$$

- consumption of fruits and vegetables. Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 9 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-grown produce

The consumption of produce exposure route drives the PRGs lower than all the other routes. It is recommended that produce-specific transfer factors (Bv_{wet}) be used when available for a site. Further, the default transfer factors (Bv_{wet}) from IAEA, used in these PRG calculations, are based on a composite of all soil groups. Transfer factors (Bv_{wet}) for sand, loam, clay, organic, coral sand, and other soil types that may be more suited to a particular site are also provided. The site-specific option of the calculator can be used to focus on ingestion of individual produce types. When "Site-Specific" is selected, if the user changes the "Select Isotope Info Type" to "User-provided", then a specific transfer factor may be changed.

$$CDI_{\text{far-soil-produce-ing-tot}} (\text{pCi}) = \sum_{i=1}^n CDI_{\text{far-soil-produce-ing}} (\text{pCi})_i$$

where:

n = total number of produce items included

and:

$$CDI_{\text{far-soil-produce-ing}} (\text{pCi}) = C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times (R_{\text{upv}} + R_{\text{es}}) \times IF_{\text{far-adj}} (\text{g}) \times CF_{\text{far-produce}} (1)$$

where:

$$R_{\text{upv}} = Bv_{\text{wet}} \left(\frac{\text{pCi/g-fresh plant}}{\text{pCi/g-dry soil}} \right); R_{\text{es}} = MLF_{\text{produce}} \left(\frac{\text{g-dry soil}}{\text{g-fresh plant}} \right)$$

and:

$$IF_{\text{far-adj}} (\text{g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IR_{\text{far-c}} \left(\frac{\text{g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IR_{\text{far-a}} \left(\frac{\text{g}}{\text{day}} \right) \right) \right)$$

where:

$$CDI_{\text{far-produce-ing-tot}} (\text{pCi}) = \sum_{i=1}^n CDI_{\text{far-produce-ing}} (\text{pCi})_i$$

where:

n = total number of produce items included

and:

$$CDI_{\text{far-produce-ing}} (\text{pCi}) = C_{\text{produce}} \left(\frac{\text{pCi}}{\text{g}} \right) \times IF_{\text{far-adj}} (\text{g}) \times CF_{\text{far-produce}} (1)$$

where:

$$IF_{\text{far-adj}} (\text{g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IR_{\text{far-c}} \left(\frac{\text{g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IR_{\text{far-a}} \left(\frac{\text{g}}{\text{day}} \right) \right) \right)$$

- consumption of poultry. Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced poultry.

$$CDI_{\text{far-soil-poultry-ing}}(\text{pCi}) = \left(\left[C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times IFF_{\text{far-adj}}(2,190,930 \text{ g}) \times CF_{\text{far-poultry}}(1) \times TF_{\text{poultry}} \left(\frac{\text{day}}{\text{kg}} \right) \times \left(Q_{\text{p-poultry}} \left(\frac{0.2 \text{ kg}}{\text{day}} \right) \times f_{\text{p-poultry}}(1) \times f_{\text{s-poultry}}(1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-poultry}} \left(\frac{0.022 \text{ kg}}{\text{day}} \right) \times f_{\text{p-poultry}}(1) \right) \right] \right)$$

where:

$$R_{\text{upp}} = Bv_{\text{dry}} \left(\frac{\text{pCi / g-dry plant}}{\text{pCi / g-dry soil}} \right); R_{\text{es}} = \text{MLF}_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{\text{g-dry plant}} \right)$$

and:

$$IFF_{\text{far-adj}}(2,190,930 \text{ g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}}(6 \text{ years}) \times IRP_{\text{far-c}} \left(\frac{48.8 \text{ g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}}(34 \text{ years}) \times IRP_{\text{far-a}} \left(\frac{175.5 \text{ g}}{\text{day}} \right) \right) \right)$$

- **consumption of eggs.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced eggs.

$$CDI_{\text{far-soil-egg-ing}}(\text{pCi}) = \left(\left[C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times IFE_{\text{far-adj}}(1,210,580 \text{ g}) \times CF_{\text{far-egg}}(1) \times TF_{\text{egg}} \left(\frac{\text{day}}{\text{kg}} \right) \times \left(Q_{\text{p-poultry}} \left(\frac{0.2 \text{ kg}}{\text{day}} \right) \times f_{\text{p-poultry}}(1) \times f_{\text{s-poultry}}(1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-poultry}} \left(\frac{0.022 \text{ kg}}{\text{day}} \right) \times f_{\text{p-poultry}}(1) \right) \right] \right)$$

where:

$$R_{\text{upp}} = Bv_{\text{dry}} \left(\frac{\text{pCi / g-dry plant}}{\text{pCi / g-dry soil}} \right); R_{\text{es}} = \text{MLF}_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{\text{g-dry plant}} \right)$$

and:

$$IFE_{\text{far-adj}}(1,210,580 \text{ g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}}(6 \text{ years}) \times IRE_{\text{far-c}} \left(\frac{25.1 \text{ g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}}(34 \text{ years}) \times IRE_{\text{far-a}} \left(\frac{97.3 \text{ g}}{\text{day}} \right) \right) \right)$$

- **consumption of beef.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced beef.

$$CDI_{\text{far-soil-beef-ing}}(\text{pCi}) = \left(\left[C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times IFB_{\text{far-adj}}(3,349,850 \text{ g}) \times CF_{\text{far-beef}}(1) \times TF_{\text{beef}} \left(\frac{\text{day}}{\text{kg}} \right) \times \left(Q_{\text{p-beef}} \left(\frac{11.77 \text{ kg}}{\text{day}} \right) \times f_{\text{p-beef}}(1) \times f_{\text{s-beef}}(1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-beef}} \left(\frac{0.5 \text{ kg}}{\text{day}} \right) \times f_{\text{p-beef}}(1) \right) \right] \right)$$

where:

$$R_{\text{upp}} = Bv_{\text{dry}} \left(\frac{\text{pCi / g-dry plant}}{\text{pCi / g-dry soil}} \right); R_{\text{es}} = \text{MLF}_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{\text{g-dry plant}} \right)$$

and:

$$IFB_{\text{far-adj}}(3,349,850 \text{ g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}}(6 \text{ years}) \times IRB_{\text{far-c}} \left(\frac{64.6 \text{ g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}}(34 \text{ years}) \times IRB_{\text{far-a}} \left(\frac{270.1 \text{ g}}{\text{day}} \right) \right) \right)$$

- **consumption of dairy.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced dairy.

$$CDI_{\text{far-soil-dairy-ing}} (pCiL^2) = \left(C_{\text{soil}} \left(\frac{pCi}{g} \right) \times IFD_{\text{far-adj}} (19,456,640 \text{ g}) \times CF_{\text{far-dairy}} (1) \times TF_{\text{dairy}} \left(\frac{\text{day}}{L \text{ milk}} \right) \times \right. \\ \left. p_m (1.03 \text{ kg})^{-1} \times \left[\left(Q_{\text{p-dairy}} \left(\frac{20.3 \text{ kg}}{\text{day}} \right) \times f_{\text{p-dairy}} (1) \times f_{\text{s-dairy}} (1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \right. \right. \\ \left. \left. \left(Q_{\text{s-dairy}} \left(\frac{0.4 \text{ kg}}{\text{day}} \right) \times f_{\text{p-dairy}} (1) \right) \right] \right)$$

where:

$$R_{\text{upp}} = Bv_{\text{dry}} \left(\frac{pCi / g\text{-dry plant}}{pCi / g\text{-dry soil}} \right); R_{\text{es}} = MLF_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{g\text{-dry plant}} \right)$$

and:

$$IFD_{\text{far-adj}} (19,456,640 \text{ g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IRD_{\text{far-c}} \left(\frac{1116.4 \text{ g}}{\text{day}} \right) \right) + \right. \\ \left. \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IRD_{\text{far-a}} \left(\frac{1438.0 \text{ g}}{\text{day}} \right) \right) \right)$$

- **consumption of swine.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced swine.

$$CDI_{\text{far-soil-swine-ing}} (pCi) = \left(C_{\text{soil}} \left(\frac{pCi}{g} \right) \times IFSW_{\text{far-adj}} (1,865,710 \text{ g}) \times CF_{\text{far-swine}} (1) \times TF_{\text{swine}} \left(\frac{\text{day}}{\text{kg}} \right) \times \right. \\ \left. \left[\left(Q_{\text{p-swine}} \left(\frac{4.7 \text{ kg}}{\text{day}} \right) \times f_{\text{p-swine}} (1) \times f_{\text{s-swine}} (1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \right. \right. \\ \left. \left. \left(Q_{\text{s-swine}} \left(\frac{0.37 \text{ kg}}{\text{day}} \right) \times f_{\text{p-swine}} (1) \right) \right] \right)$$

where:

$$R_{\text{upp}} = Bv_{\text{dry}} \left(\frac{pCi / g\text{-dry plant}}{pCi / g\text{-dry soil}} \right); R_{\text{es}} = MLF_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{g\text{-dry plant}} \right)$$

and:

$$IFSW_{\text{far-adj}} (1,865,710 \text{ g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IRSW_{\text{far-c}} \left(\frac{32.2 \text{ g}}{\text{day}} \right) \right) + \right. \\ \left. \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IRSW_{\text{far-a}} \left(\frac{151.1 \text{ g}}{\text{day}} \right) \right) \right)$$

- **consumption of fin fish.** Chapters 10 and 13 of the 2011 [Exposure Factors Handbook](#) were used to derive the intakes for home-caught fin fish.

$$CDI_{\text{far-soil-finfish-ing}} (pCi) = \frac{C_{\text{soil}} \left(\frac{pCi}{g} \right) \times BCF \left(\frac{L}{kg} \right)}{Kd \left(\frac{L}{kg} \right)} \times IFFI_{\text{far-adj}} (1,931,020 \text{ g}) \times CF_{\text{far-finfish}} (1)$$

where:

$$IFFI_{\text{far-adj}} (1,931,020 \text{ g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IRFI_{\text{far-c}} \left(\frac{36.1 \text{ g}}{\text{day}} \right) \right) + \right. \\ \left. \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IRFI_{\text{far-a}} \left(\frac{155.9 \text{ g}}{\text{day}} \right) \right) \right)$$

- **consumption of shellfish.** Table 10-9 of the 2011 [Exposure Factors Handbook](#) was used to derive the intakes for home-caught shellfish.

$$CDI_{\text{far-soil-shellfish-ing}} (pCi) = \frac{C_{\text{soil}} \left(\frac{pCi}{g} \right) \times BCF \left(\frac{L}{kg} \right)}{Kd \left(\frac{L}{kg} \right)} \times IFSF_{\text{far-adj}} (2,530,640 \text{ g}) \times CF_{\text{far-shellfish}} (1)$$

where:

$$IFSF_{\text{far-adj}} (2,530,640 \text{ g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IRSF_{\text{far-c}} \left(\frac{21.3 \text{ g}}{\text{day}} \right) \right) + \right. \\ \left. \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IRSF_{\text{far-a}} \left(\frac{208.9 \text{ g}}{\text{day}} \right) \right) \right)$$

The following consumption routes are provided in site-specific mode only and require the user to enter their own data, as the tool only provides a transfer factor.

- **consumption of goat.**

$$CDI_{\text{far-soil-goat-ing}}(\text{pCi}) = \left[\left(C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times IFGO_{\text{far-adj}}(\text{g}) \times CF_{\text{far-goat}}(1) \times TF_{\text{goat}} \left(\frac{\text{day}}{\text{kg}} \right) \times \left[\left(Q_{\text{p-goat}} \left(\frac{1.27 \text{ kg}}{\text{day}} \right) \times f_{\text{p-goat}}(1) \times f_{\text{s-goat}}(1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-goat}} \left(\frac{0.23 \text{ kg}}{\text{day}} \right) \times f_{\text{p-goat}}(1) \right) \right] \right) \right]$$

where:

$$R_{\text{upp}} = Bv_{\text{dry}} \left(\frac{\text{pCi} / \text{g-dry plant}}{\text{pCi} / \text{g-dry soil}} \right); R_{\text{es}} = MLF_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{\text{g-dry plant}} \right)$$

and:

$$IFGO_{\text{far-adj}}(\text{g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}}(6 \text{ years}) \times IRGO_{\text{far-c}} \left(\frac{\text{g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}}(34 \text{ years}) \times IRGO_{\text{far-a}} \left(\frac{\text{g}}{\text{day}} \right) \right) \right)$$

- consumption of goat milk.

$$CDI_{\text{far-soil-goat-milk-ing}}(\text{pCi}) = \left[\left(C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times IFGM_{\text{far-adj}}(\text{g}) \times CF_{\text{far-goat-milk}}(1) \times TF_{\text{goat-milk}} \left(\frac{\text{day}}{\text{kg}} \right) \times \rho_m \left(\frac{1.03 \text{ kg}}{1 \text{ L milk}} \right)^{-1} \times \left[\left(Q_{\text{p-goat-milk}} \left(\frac{1.59 \text{ kg}}{\text{day}} \right) \times f_{\text{p-goat-milk}}(1) \times f_{\text{s-goat-milk}}(1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-goat-milk}} \left(\frac{0.29 \text{ kg}}{\text{day}} \right) \times f_{\text{p-goat-milk}}(1) \right) \right] \right) \right]$$

where:

$$R_{\text{upp}} = Bv_{\text{dry}} \left(\frac{\text{pCi} / \text{g-dry plant}}{\text{pCi} / \text{g-dry soil}} \right); R_{\text{es}} = MLF_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{\text{g-dry plant}} \right)$$

and:

$$IFGM_{\text{far-adj}}(\text{g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}}(6 \text{ years}) \times IRGM_{\text{far-c}} \left(\frac{\text{g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}}(34 \text{ years}) \times IRGM_{\text{far-a}} \left(\frac{\text{g}}{\text{day}} \right) \right) \right)$$

- consumption of sheep.

$$CDI_{\text{far-soil-sheep-ing}}(\text{pCi/g}) = \left[\left(C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times IFSH_{\text{far-adj}}(\text{g}) \times CF_{\text{far-sheep}}(1) \times TF_{\text{sheep}} \left(\frac{\text{day}}{\text{kg}} \right) \times \left[\left(Q_{\text{p-sheep}} \left(\frac{1.75 \text{ kg}}{\text{day}} \right) \times f_{\text{p-sheep}}(1) \times f_{\text{s-sheep}}(1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-sheep}} \left(\frac{0.32 \text{ kg}}{\text{day}} \right) \times f_{\text{p-sheep}}(1) \right) \right] \right) \right]$$

where:

$$R_{\text{upp}} = Bv_{\text{dry}} \left(\frac{\text{pCi} / \text{g-dry plant}}{\text{pCi} / \text{g-dry soil}} \right); R_{\text{es}} = MLF_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{\text{g-dry plant}} \right)$$

and:

$$IFSH_{\text{far-adj}}(\text{g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}}(6 \text{ years}) \times IRSH_{\text{far-c}} \left(\frac{\text{g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}}(34 \text{ years}) \times IRSH_{\text{far-a}} \left(\frac{\text{g}}{\text{day}} \right) \right) \right)$$

- consumption of sheep milk.

$$CDI_{\text{far-soil-sheep-milk-ing}}(\text{pCi/g}) = \left[\left(C_{\text{soil}} \left(\frac{\text{pCi}}{\text{g}} \right) \times IFSM_{\text{far-adj}}(\text{g}) \times CF_{\text{far-sheep-milk}}(1) \times TF_{\text{sheep-milk}} \left(\frac{\text{day}}{\text{L milk}} \right) \times \rho_m \left(\frac{1.03 \text{ kg}}{1 \text{ L milk}} \right)^{-1} \times \left[\left(Q_{\text{p-sheep-milk}} \left(\frac{3.15 \text{ kg}}{\text{day}} \right) \times f_{\text{p-sheep-milk}}(1) \times f_{\text{s-sheep-milk}}(1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-sheep-milk}} \left(\frac{0.57 \text{ kg}}{\text{day}} \right) \times f_{\text{p-sheep-milk}}(1) \right) \right] \right) \right]$$

where:

$$R_{\text{upp}} = Bv_{\text{dry}} \left(\frac{\text{pCi} / \text{g-dry plant}}{\text{pCi} / \text{g-dry soil}} \right); R_{\text{es}} = MLF_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{\text{g-dry plant}} \right)$$

and:

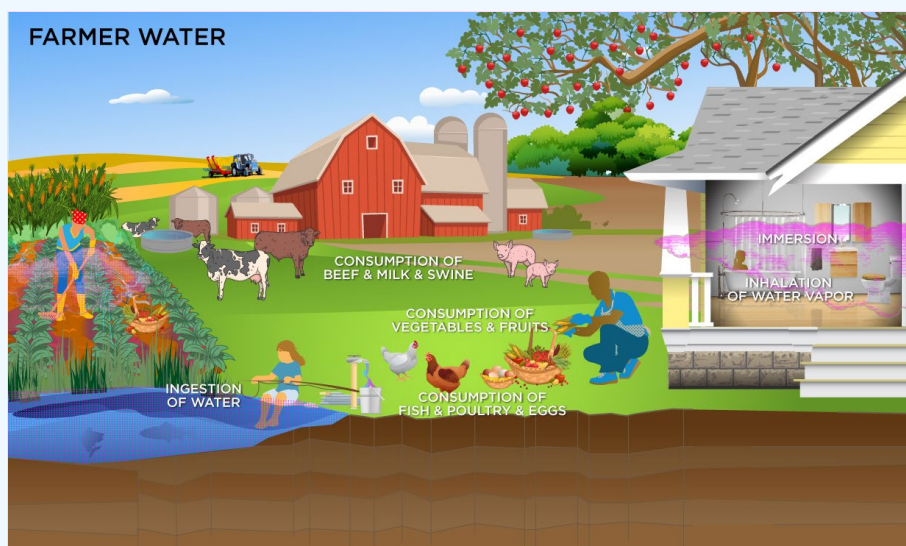
$$IFSM_{\text{far-adj}}(\text{g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}}(6 \text{ years}) \times IRSM_{\text{far-c}} \left(\frac{\text{g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}}(34 \text{ years}) \times IRSM_{\text{far-a}} \left(\frac{\text{g}}{\text{day}} \right) \right) \right)$$

Definitions of the input variables are in [Table 1](#).

4.8.3 Farmer Direct Exposure and Consumption of Agricultural Products - Combined Water and Biota

The farmer scenario should be considered an extension of the resident scenario and evaluates consumption of farm products for a subsistence farmer. Like the resident, the source of the contamination, such as groundwater vs. surface water, is not relevant to the calculations and assumes the receptor will be exposed via the following pathways: ingestion of tapwater, external radiation from contaminants in tapwater, and inhalation of gases in tapwater and consumption of home grown produce (100% of fruit and vegetables are from the farm). The inhalation exposure route is only calculated for C-14, H-3, Rn-219, Rn-220, Rn-222, and the radon short-lived progeny that remain airborne for a time. If a user selects an isotope that decays into one of the three radons (i.e., Ac-227, Pu-240, U-238, etc.), the inhalation route will be calculated for radon and its short-lived progeny. The farmer default air exchange rate is set at 0.18 per hour. When the calculator is operated in site-specific mode, the user can adjust the air exchange rate that alters the levels of radon progeny in the air available for inhalation. Section 4.10.8 presents the details of the radon progeny included in the tapwater inhalation route. External exposure to immersion in tapwater and exposure to produce irrigated with contaminated tapwater are also considered. In addition to produce, 100% of consumption of the following are also considered to be from the farm: beef, dairy, fin fish, shellfish, swine, egg, and poultry. All water (100%) for farm products is considered to have been provided from contaminated portions of the site. For these farm products, risk-based PRGs are provided for the water that may contribute contaminants to the products. Also like the resident, age-adjusted intake equations were developed for all of the ingestion/consumption equations to account for changes in intake as the receptor ages.

Graphical Representation



PRG Equations

- ingestion of tapwater,

$$PRG_{\text{far-water-ing}} (\text{pCi/L}) = \frac{TR}{SF_{\text{water}} \left(\frac{\text{risk}}{\text{pCi}} \right) \times \left(IFW_{\text{far-adj}} (31,388 \text{ L}) \right)}$$

where:

$$IFW_{\text{far-adj}} (31,388 \text{ L}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IRW_{\text{far-c}} \left(\frac{0.78 \text{ L}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IRW_{\text{far-a}} \left(\frac{2.5 \text{ L}}{\text{day}} \right) \right) \right)$$

- **inhalation**, (The inhalation exposure route is only calculated for C-14 and H-3 as well as Rn-222, Rn-220, and Rn-219, including their short-lived progeny. Also, volatilization in the equation comes from household uses of water (e.g., showering, laundering, dish washing)).

$$PRG_{\text{far-water-inh}} (\text{pCi/L}) = \frac{TR}{SF_i \left(\frac{\text{risk}}{\text{pCi}} \right) \times IFA_{\text{far-adj}} (259,000 \text{ m}^3) \times K \left(\frac{0.5 \text{ L}}{\text{m}^3} \right)}$$

where:

$$IFA_{\text{far-adj}} (259,000 \text{ m}^3) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times ET_{\text{far-c}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{\text{far-c}} \left(\frac{10 \text{ m}^3}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times ET_{\text{far-a}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{\text{far-a}} \left(\frac{20 \text{ m}^3}{\text{day}} \right) \right) \right)$$

- immersion in tapwater,

$$PRG_{\text{far-water-imm}} (\text{pCi/L}) = \frac{TR}{SF_{\text{imm}} \left(\frac{\text{risk/yr}}{\text{pCi/L}} \right) \times DFA_{\text{far-adj}} (9,583 \text{ hours}) \times \left(\frac{1 \text{ year}}{8760 \text{ hours}} \right)}$$

where:

$$DFA_{\text{far-adj}} (9,583 \text{ hours}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times EV_{\text{far-c}} \left(\frac{1 \text{ event}}{\text{day}} \right) \times ET_{\text{event-far-c}} \left(\frac{0.54 \text{ hours}}{\text{event}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times EV_{\text{far-a}} \left(\frac{1 \text{ event}}{\text{day}} \right) \times ET_{\text{event-far-a}} \left(\frac{0.71 \text{ hours}}{\text{event}} \right) \right) \right)$$

- consumption of fruits and vegetables. Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 9 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-grown produce

The consumption of produce exposure route drives the PRGs lower than all the other routes. It is recommended that produce-specific transfer factors (B_{wet}) be used when available for a site. Further, the default transfer factors (B_{wet}) from IAEA, used in these PRG calculations, are based on a composite of all soil groups. Transfer factors (B_{wet}) for sand, loam, clay, organic, coral sand, and other soil types that may be more suited to a particular site are also provided. The site-specific option of the calculator can be used to focus on ingestion of individual produce types. When "Site-Specific" is selected, if the user changes the "Select Isotope Info Type" to "User-provided", then a specific transfer factor may be changed.

$$PRG_{\text{far-water-produce-ing-tot}} (\text{pCi/L}) = \frac{1}{\sum_{i=1}^n \frac{1}{PRG_{\text{far-water-produce-ing}} (\text{pCi/L})_i}}$$

where:

n = total number of produce items included

and:

$$PRG_{\text{far-water-produce-ing}} (\text{pCi/L}) = \frac{PRG_{\text{far-produce-ing}} (\text{pCi/g})}{\left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \times \left(Irr_{\text{rup}} \left(\frac{\text{L}}{\text{kg}} \right) + Irr_{\text{res}} \left(\frac{\text{L}}{\text{kg}} \right) + Irr_{\text{dep}} \left(\frac{\text{L}}{\text{kg}} \right) \right)}$$

where:

$$Irr_{\text{res}} \left(\frac{\text{L}}{\text{kg}} \right) = \frac{Ir \left(\frac{\text{L}}{\text{m}^2 \cdot \text{day}} \right) \times F \times MLF_{\text{produce}} \times \left[1 - \exp \left(- \left(\frac{\lambda_B}{\text{day}} \right) \times t_b (\text{days}) \right) \right]}{P \left(\frac{\text{kg}}{\text{m}^2} \right) \times \left(\frac{\lambda_B}{\text{day}} \right)}$$

$$Irr_{\text{rup}} \left(\frac{\text{L}}{\text{kg}} \right) = \frac{Ir \left(\frac{\text{L}}{\text{m}^2 \cdot \text{day}} \right) \times F \times B_{\text{wet}} \times \left[1 - \exp \left(- \left(\frac{\lambda_B}{\text{day}} \right) \times t_b (\text{days}) \right) \right]}{P \left(\frac{\text{kg}}{\text{m}^2} \right) \times \left(\frac{\lambda_B}{\text{day}} \right)}$$

and:

$$Irr_{\text{dep}} \left(\frac{\text{L}}{\text{kg}} \right) = \frac{Ir \left(\frac{\text{L}}{\text{m}^2 \cdot \text{day}} \right) \times F \times I_f \times T \times \left[1 - \exp \left(- \left(\frac{\lambda_E}{\text{day}} \right) \times t_v (\text{days}) \right) \right]}{Y_v \left(\frac{\text{kg}}{\text{m}^2} \right) \times \left(\frac{\lambda_E}{\text{day}} \right)}$$

where:

$$PRG_{\text{far-produce-ing-tot}} (\text{pCi/g}) = \frac{1}{\left(\sum_{i=1}^n \frac{1}{PRG_{\text{far-produce-ing}} (\text{pCi/g})_i} \right)}$$

where:

n = total number of produce items included

and:

$$PRG_{\text{far-produce-ing}} (\text{pCi/g}) = \frac{TR}{SF_f \left(\frac{\text{risk}}{\text{pCi}} \right) \times IF_{\text{far-adj}} (\text{g}) \times CF_{\text{far-produce}} (1)}$$

where:

$$IF_{\text{far-adj}} (\text{g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IR_{\text{far-c}} \left(\frac{\text{g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IR_{\text{far-a}} \left(\frac{\text{g}}{\text{day}} \right) \right) \right)$$

- **consumption of poultry.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced poultry.

$$PRG_{\text{far-water-poultry-ing}} (\text{pCi/L}) = \frac{PRG_{\text{far-poultry-ing}} (\text{pCi/g})}{TF_{\text{poultry}} \left(\frac{\text{day}}{\text{kg}} \right) \times Q_{\text{w-poultry}} \left(\frac{0.4 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right)}$$

- **consumption of eggs.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced eggs.

$$PRG_{\text{far-water-egg-ing}} (\text{pCi/L}) = \frac{PRG_{\text{far-egg-ing}} (\text{pCi/g})}{TF_{\text{egg}} \left(\frac{\text{day}}{\text{kg}} \right) \times Q_{\text{w-poultry}} \left(\frac{0.4 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right)}$$

- **consumption of beef.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced beef.

$$PRG_{\text{far-water-beef-ing}} (\text{pCi/L}) = \frac{PRG_{\text{far-beef-ing}} (\text{pCi/g})}{TF_{\text{beef}} \left(\frac{\text{day}}{\text{kg}} \right) \times Q_{\text{w-beef}} \left(\frac{53 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right)}$$

- **consumption of dairy.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced dairy.

$$PRG_{\text{far-water-dairy-ing}} (\text{pCi/L}) = \frac{PRG_{\text{far-dairy-ing}} (\text{pCi/g})}{TF_{\text{dairy}} \left(\frac{\text{day}}{\text{L milk}} \right) \times \rho_m \left(\frac{1.03 \text{ kg}}{1 \text{ L milk}} \right)^{-1} \times Q_{\text{w-dairy}} \left(\frac{92 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right)}$$

- **consumption of swine.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced swine.

$$PRG_{\text{far-water-swine-ing}} (\text{pCi/L}) = \frac{PRG_{\text{far-swine-ing}} (\text{pCi/g})}{TF_{\text{sw}} \left(\frac{\text{day}}{\text{kg}} \right) \times Q_{\text{w-swine}} \left(\frac{11.4 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right)}$$

- **consumption of fin fish.** Chapters 10 and 13 of the 2011 [Exposure Factors Handbook](#) were used to derive the intakes for home-caught fin fish.

$$PRG_{\text{far-water-finish-ing}} (\text{pCi/L}) = \frac{PRG_{\text{far-finish-ing}} (\text{pCi/g})}{BCF \left(\frac{\text{L}}{\text{kg}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right)}$$

- **consumption of shellfish.** Table 10-9 of the 2011 [Exposure Factors Handbook](#) was used to derive the intakes for home-caught shellfish.

$$PRG_{\text{far-water-shellfish-ing}} (\text{pCi/L}) = \frac{PRG_{\text{far-shellfish-ing}} (\text{pCi/g})}{BCF \left(\frac{\text{L}}{\text{kg}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right)}$$

- total

$$\text{PRG}_{\text{wat-far-tot}} (\text{pCi/L}) = \frac{\text{PRG}_{\text{far-water-ing}} + \text{PRG}_{\text{far-water-far-inh}} + \text{PRG}_{\text{far-water-far-imm}} + \text{PRG}_{\text{far-water-far-produce-ing-tot}} + \text{PRG}_{\text{far-water-far-egg-ing}} + \text{PRG}_{\text{far-water-far-poultry-ing}}}{\text{PRG}_{\text{far-water-far-fish-ing}} + \text{PRG}_{\text{far-water-far-shellfish-ing}} + \text{PRG}_{\text{far-water-far-beef-ing}} + \text{PRG}_{\text{far-water-far-dairy-ing}} + \text{PRG}_{\text{far-water-far-swine-ing}}}$$

The following consumption routes are provided in site-specific mode only and require the user to enter their own data, as the tool only provides a transfer factor.

- consumption of goat.

$$\text{PRG}_{\text{far-water-goat-ing}} (\text{pCi/L}) = \frac{\text{PRG}_{\text{far-goat-ing}} (\text{pCi/g})}{\text{TF}_{\text{goat}} \left(\frac{\text{day}}{\text{kg}} \right) \times Q_{\text{w-goat}} \left(\frac{3.81 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right)}$$

- consumption of goat milk.

$$\text{PRG}_{\text{far-water-goat-milk-ing}} (\text{pCi/L}) = \frac{\text{PRG}_{\text{far-goat-milk-ing}} (\text{pCi/g})}{\text{TF}_{\text{goat-milk}} \left(\frac{\text{day}}{\text{L milk}} \right) \times \rho_m \left(\frac{1.03 \text{ kg}}{1 \text{ L milk}} \right)^{-1} \times Q_{\text{w-goat-milk}} \left(\frac{8.75 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right)}$$

- consumption of sheep.

$$\text{PRG}_{\text{far-water-sheep-ing}} (\text{pCi/L}) = \frac{\text{PRG}_{\text{far-sheep-ing}} (\text{pCi/g})}{\text{TF}_{\text{sheep}} \left(\frac{\text{day}}{\text{kg}} \right) \times Q_{\text{w-sheep}} \left(\frac{5.25 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right)}$$

- consumption of sheep milk.

$$\text{PRG}_{\text{far-water-sheep-milk-ing}} (\text{pCi/L}) = \frac{\text{PRG}_{\text{far-sheep-milk-ing}} (\text{pCi/g})}{\text{TF}_{\text{sheep-milk}} \left(\frac{\text{day}}{\text{L milk}} \right) \times \rho_m \left(\frac{1.03 \text{ kg}}{1 \text{ L milk}} \right)^{-1} \times Q_{\text{w-sheep-milk}} \left(\frac{10.4 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right)}$$

Definitions of the input variables are in [Table 1](#).

CDI Equations

- ingestion of tapwater,

$$\text{CDI}_{\text{far-water-ing}} (\text{pCi}) = C_{\text{g-water}} \left(\frac{\text{pCi}}{\text{L}} \right) \times \left(\text{IFW}_{\text{far-adj}} (31,388 \text{ L}) \right)$$

where:

$$\text{IFW}_{\text{far-adj}} (31,388 \text{ L}) = \left(\left(\text{EF}_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \text{ED}_{\text{far-c}} (6 \text{ years}) \times \text{IRW}_{\text{far-c}} \left(\frac{0.78 \text{ L}}{\text{day}} \right) \right) + \left(\text{EF}_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \text{ED}_{\text{far-a}} (34 \text{ years}) \times \text{RW}_{\text{far-a}} \left(\frac{2.5 \text{ L}}{\text{day}} \right) \right) \right)$$

- **inhalation**, (The inhalation exposure route is only calculated for C-14 and H-3 as well as Rn-222, Rn-220, and Rn-219, including their short-lived progeny. Also, volatilization in the equation comes from household uses of water (e.g., showering, laundering, dish washing)).

$$\text{CDI}_{\text{far-water-inh}} (\text{pCi}) = C_{\text{g-water}} \left(\frac{\text{pCi}}{\text{L}} \right) \times \text{IFA}_{\text{far-adj}} (259,000 \text{ m}^3) \times k \left(\frac{0.5 \text{ L}}{\text{m}^3} \right)$$

where:

$$\text{IFA}_{\text{far-adj}} (259,000 \text{ m}^3) = \left(\left(\text{EF}_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \text{ED}_{\text{far-c}} (6 \text{ years}) \times \text{ET}_{\text{far-c}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{IRA}_{\text{far-c}} \left(\frac{10 \text{ m}^3}{\text{day}} \right) \right) + \left(\text{EF}_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \text{ED}_{\text{far-a}} (34 \text{ years}) \times \text{ET}_{\text{far-a}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times \text{IRA}_{\text{far-a}} \left(\frac{20 \text{ m}^3}{\text{day}} \right) \right) \right)$$

- immersion in tapwater,

$$CDI_{\text{far-water-imm}}(\text{pCi}\cdot\text{year/L}) = C_{\text{g-water}} \left(\frac{\text{pCi}}{\text{L}} \right) \times DFA_{\text{far-adj}}(9,583 \text{ hours}) \times \left(\frac{1 \text{ year}}{8760 \text{ hours}} \right)$$

where:

$$DFA_{\text{far-adj}}(9,583 \text{ hours}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}}(6 \text{ years}) \times EV_{\text{far-c}} \left(\frac{1 \text{ event}}{\text{day}} \right) \times ET_{\text{event-far-c}} \left(\frac{0.54 \text{ hours}}{\text{event}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}}(34 \text{ years}) \times EV_{\text{far-a}} \left(\frac{1 \text{ event}}{\text{day}} \right) \times ET_{\text{event-far-a}} \left(\frac{0.71 \text{ hours}}{\text{event}} \right) \right) \right)$$

- consumption of fruits and vegetables. Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 9 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-grown produce

The consumption of produce exposure route drives the PRGs lower than all the other routes. It is recommended that produce-specific transfer factors (Bv_{wet}) be used when available for a site. Further, the default transfer factors (Bv_{wet}) from IAEA, used in these PRG calculations, are based on a composite of all soil groups. Transfer factors (Bv_{wet}) for sand, loam, clay, organic, coral sand, and other soil types that may be more suited to a particular site are also provided. The site-specific option of the calculator can be used to focus on ingestion of individual produce types. When "Site-Specific" is selected, if the user changes the "Select Isotope Info Type" to "User-provided", then a specific transfer factor may be changed.

$$CDI_{\text{far-water-produce-tot}}(\text{pCi}) = \sum_{i=1}^n CDI_{\text{far-water-produce-ing}}(\text{pCi}_i)$$

where:

n = total number of produce items included

and:

$$CDI_{\text{far-water-produce}}(\text{pCi}) = \left(C_{\text{g-water}} \left(\frac{\text{pCi}}{\text{L}} \right) \times IF_{\text{far-adj}}(\text{g}) \times CF_{\text{far-produce}}(1) \times \left[\left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \times \left(Irr_{\text{rup}} \left(\frac{\text{L}}{\text{kg}} \right) + Irr_{\text{res}} \left(\frac{\text{L}}{\text{kg}} \right) + Irr_{\text{dep}} \left(\frac{\text{L}}{\text{kg}} \right) \right] \right)$$

where:

$$Irr_{\text{res}} \left(\frac{\text{L}}{\text{kg}} \right) = \frac{I_r \left(\frac{\text{L}}{\text{m}^2\text{-day}} \right) \times F \times MLF_{\text{produce}} \times \left[1 - \exp \left(- \left(\frac{\lambda_B}{\text{day}} \right) \times t_b(\text{days}) \right) \right]}{P \left(\frac{\text{kg}}{\text{m}^2} \right) \times \left(\frac{\lambda_B}{\text{day}} \right)}$$

$$Irr_{\text{rup}} \left(\frac{\text{L}}{\text{kg}} \right) = \frac{I_r \left(\frac{\text{L}}{\text{m}^2\text{-day}} \right) \times F \times Bv_{\text{wet}} \times \left[1 - \exp \left(- \left(\frac{\lambda_B}{\text{day}} \right) \times t_b(\text{days}) \right) \right]}{P \left(\frac{\text{kg}}{\text{m}^2} \right) \times \left(\frac{\lambda_B}{\text{day}} \right)}$$

and:

$$Irr_{\text{dep}} \left(\frac{\text{L}}{\text{kg}} \right) = \frac{I_r \left(\frac{\text{L}}{\text{m}^2\text{-day}} \right) \times F \times I_f \times T \times \left[1 - \exp \left(- \left(\frac{\lambda_E}{\text{day}} \right) \times t_v(\text{days}) \right) \right]}{Y_v \left(\frac{\text{kg}}{\text{m}^2} \right) \times \left(\frac{\lambda_E}{\text{day}} \right)}$$

and:

$$IF_{\text{far-adj}}(\text{g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}}(6 \text{ years}) \times IR_{\text{far-c}} \left(\frac{\text{g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}}(34 \text{ years}) \times IR_{\text{far-a}} \left(\frac{\text{g}}{\text{day}} \right) \right) \right)$$

where:

$$CDI_{\text{far-produce-ing-tot}}(\text{pCi}) = \sum_{i=1}^n CDI_{\text{far-produce-ing}}(\text{pCi}_i)$$

where:

n = total number of produce items included

and:

$$CDI_{\text{far-produce-ing}}(\text{pCi}) = C_{\text{produce}} \left(\frac{\text{pCi}}{\text{g}} \right) \times IF_{\text{far-adj}}(\text{g}) \times CF_{\text{far-produce}}(1)$$

where:

$$IF_{\text{far-adj}}(\text{g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}}(6 \text{ years}) \times IR_{\text{far-c}} \left(\frac{\text{g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}}(34 \text{ years}) \times IR_{\text{far-a}} \left(\frac{\text{g}}{\text{day}} \right) \right) \right)$$

- **consumption of poultry.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced poultry.

$$CDI_{\text{far-water-poultry-ing}} (\text{pCi}) = \left(\begin{array}{l} C_{\text{g-water}} \left(\frac{\text{pCi}}{\text{L}} \right) \times IFP_{\text{far-adj}} (2,190,930 \text{ g}) \times CF_{\text{far-poultry}} (1) \times \\ \left[TF_{\text{poultry}} \left(\frac{\text{day}}{\text{kg}} \right) \times Q_{\text{w-poultry}} \left(\frac{0.4 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \right] \end{array} \right)$$

where:

$$IFP_{\text{far-adj}} (2,190,930 \text{ g}) = \left(\begin{array}{l} \left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IRP_{\text{far-c}} \left(\frac{48.8 \text{ g}}{\text{day}} \right) \right) + \\ \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IRP_{\text{far-a}} \left(\frac{175.5 \text{ g}}{\text{day}} \right) \right) \end{array} \right)$$

- **consumption of eggs.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced eggs.

$$CDI_{\text{far-water-egg-ing}} (\text{pCi}) = \left(\begin{array}{l} C_{\text{g-water}} \left(\frac{\text{pCi}}{\text{L}} \right) \times IFE_{\text{far-adj}} (1,210,580 \text{ g}) \times CF_{\text{far-egg}} (1) \times \\ \left[TF_{\text{egg}} \left(\frac{\text{day}}{\text{kg}} \right) \times Q_{\text{w-poultry}} \left(\frac{0.4 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \right] \end{array} \right)$$

where:

$$IFE_{\text{far-adj}} (1,210,580 \text{ g}) = \left(\begin{array}{l} \left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IRE_{\text{far-c}} \left(\frac{25.1 \text{ g}}{\text{day}} \right) \right) + \\ \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IRE_{\text{far-a}} \left(\frac{97.3 \text{ g}}{\text{day}} \right) \right) \end{array} \right)$$

- **consumption of beef.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced beef.

$$CDI_{\text{far-water-beef-ing}} (\text{pCi}) = \left(\begin{array}{l} C_{\text{g-water}} \left(\frac{\text{pCi}}{\text{L}} \right) \times IFB_{\text{far-adj}} (3,349,850 \text{ g}) \times CF_{\text{far-beef}} (1) \times \\ \left[TF_{\text{beef}} \left(\frac{\text{day}}{\text{kg}} \right) \times Q_{\text{w-beef}} \left(\frac{53 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \right] \end{array} \right)$$

where:

$$IFB_{\text{far-adj}} (3,349,850 \text{ g}) = \left(\begin{array}{l} \left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IRB_{\text{far-c}} \left(\frac{64.6 \text{ g}}{\text{day}} \right) \right) + \\ \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IRB_{\text{far-a}} \left(\frac{270.1 \text{ g}}{\text{day}} \right) \right) \end{array} \right)$$

- **consumption of dairy.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced dairy.

$$CDI_{\text{far-water-dairy-ing}} (\text{pCi}) = \left(\begin{array}{l} C_{\text{g-water}} \left(\frac{\text{pCi}}{\text{L}} \right) \times IFD_{\text{far-adj}} (19,456,640 \text{ g}) \times CF_{\text{far-dairy}} (1) \times \\ \left[TF_{\text{dairy}} \left(\frac{\text{day}}{\text{L milk}} \right) \times p_m \left(\frac{1.03 \text{ kg}}{1 \text{ L milk}} \right)^{-1} \times Q_{\text{w-dairy}} \left(\frac{92 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \right] \end{array} \right)$$

where:

$$IFD_{\text{far-adj}} (19,456,640 \text{ g}) = \left(\begin{array}{l} \left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IRD_{\text{far-c}} \left(\frac{1116.4 \text{ g}}{\text{day}} \right) \right) + \\ \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IRD_{\text{far-a}} \left(\frac{1438.0 \text{ g}}{\text{day}} \right) \right) \end{array} \right)$$

- **consumption of swine.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced swine.

$$CDI_{\text{far-water-swine-ing}} (\text{pCi}) = \left(\begin{array}{l} C_{\text{g-water}} \left(\frac{\text{pCi}}{\text{L}} \right) \times IFSW_{\text{far-adj}} (1,865,710 \text{ g}) \times CF_{\text{far-swine}} (1) \times \\ \left[TF_{\text{sw}} \left(\frac{\text{day}}{\text{kg}} \right) \times Q_{\text{w-swine}} \left(\frac{11.4 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \right] \end{array} \right)$$

where:

$$IFSW_{\text{far-adj}} (1,865,710 \text{ g}) = \left(\begin{array}{l} \left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IRSW_{\text{far-c}} \left(\frac{32.2 \text{ g}}{\text{day}} \right) \right) + \\ \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IRSW_{\text{far-a}} \left(\frac{151.1 \text{ g}}{\text{day}} \right) \right) \end{array} \right)$$

- **consumption of fin fish.** Chapters 10 and 13 of the 2011 [Exposure Factors Handbook](#) were used to derive the intakes for home-caught fin fish.

$$CDI_{\text{far-water-finish-ing}} (pCi) = C_{\text{g-water}} \left(\frac{pCi}{L} \right) \times \left[BCF \left(\frac{L}{kg} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \right] \times IFFI_{\text{far-adj}} (1,931,020 \text{ g}) \times CF_{\text{far-finish}} (1)$$

where:

$$IFFI_{\text{far-adj}} (1,931,020 \text{ g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IRFI_{\text{far-c}} \left(\frac{36.1 \text{ g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IRFI_{\text{far-a}} \left(\frac{155.9 \text{ g}}{\text{day}} \right) \right) \right)$$

- **consumption of shellfish.** Table 10-9 of the 2011 [Exposure Factors Handbook](#) was used to derive the intakes for home-caught shellfish.

$$CDI_{\text{far-water-shellfish-ing}} (pCi) = C_{\text{g-water}} \left(\frac{pCi}{L} \right) \times \left[BCF \left(\frac{L}{kg} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \right] \times IFSF_{\text{far-adj}} (2,530,640 \text{ g}) \times CF_{\text{far-shellfish}} (1)$$

where:

$$IFSF_{\text{far-adj}} (2,530,640 \text{ g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IRSF_{\text{far-c}} \left(\frac{21.3 \text{ g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IRSF_{\text{far-a}} \left(\frac{208.9 \text{ g}}{\text{day}} \right) \right) \right)$$

The following consumption routes are provided in site-specific mode only and require the user to enter their own data, as the tool only provides a transfer factor.

- **consumption of goat.**

$$CDI_{\text{far-water-goat-ing}} (pCi) = \left(C_{\text{g-water}} \left(\frac{pCi}{L} \right) \times IFGO_{\text{far-adj}} (g) \times CF_{\text{far-goat}} (1) \times \left[TF_{\text{goat}} \left(\frac{\text{day}}{\text{kg}} \right) \times Q_{\text{w-goat}} \left(\frac{3.81 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \right] \right)$$

where:

$$IFGO_{\text{far-adj}} (g) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IRGO_{\text{far-c}} \left(\frac{g}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IRGO_{\text{far-a}} \left(\frac{g}{\text{day}} \right) \right) \right)$$

- **consumption of goat milk.**

$$CDI_{\text{far-water-goat-milk-ing}} (pCi) = \left(C_{\text{g-water}} \left(\frac{pCi}{L} \right) \times IFGM_{\text{far-adj}} (g) \times CF_{\text{far-goat-milk}} (1) \times \left[TF_{\text{goat-milk}} \left(\frac{\text{day}}{L \text{ milk}} \right) \times \rho_m \left(\frac{1.03 \text{ kg}}{1 \text{ L milk}} \right)^{-1} \times Q_{\text{w-goat-milk}} \left(\frac{8.75 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \right] \right)$$

where:

$$IFGM_{\text{far-adj}} (g) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IRGM_{\text{far-c}} \left(\frac{g}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IRGM_{\text{far-a}} \left(\frac{g}{\text{day}} \right) \right) \right)$$

- **consumption of sheep.**

$$CDI_{\text{far-water-sheep-ing}} (pCi) = \left(C_{\text{g-water}} \left(\frac{pCi}{L} \right) \times IFSH_{\text{far-adj}} (g) \times CF_{\text{far-sheep}} (1) \times \left[TF_{\text{sheep}} \left(\frac{\text{day}}{\text{kg}} \right) \times Q_{\text{w-sheep}} \left(\frac{5.25 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \right] \right)$$

where:

$$IFSH_{\text{far-adj}} (g) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times IRSH_{\text{far-c}} \left(\frac{g}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times IRSH_{\text{far-a}} \left(\frac{g}{\text{day}} \right) \right) \right)$$

- **consumption of sheep milk.**

$$CDI_{\text{far-water-sheep-milk-ing}}(\text{pCi}) = \left[\begin{aligned} & C_{\text{g-water}} \left(\frac{\text{pCi}}{\text{L}} \right) \times IFSM_{\text{far-adj}}(\text{g}) \times CF_{\text{far-sheep-milk}}(1) \times \\ & \left[TF_{\text{sheep-milk}} \left(\frac{\text{day}}{\text{L milk}} \right) \times \rho_m \left(\frac{1.03 \text{ kg}}{1 \text{ L milk}} \right)^{-1} \times Q_{\text{w-sheep-milk}} \left(\frac{10.4 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \right] \end{aligned} \right]$$

where:

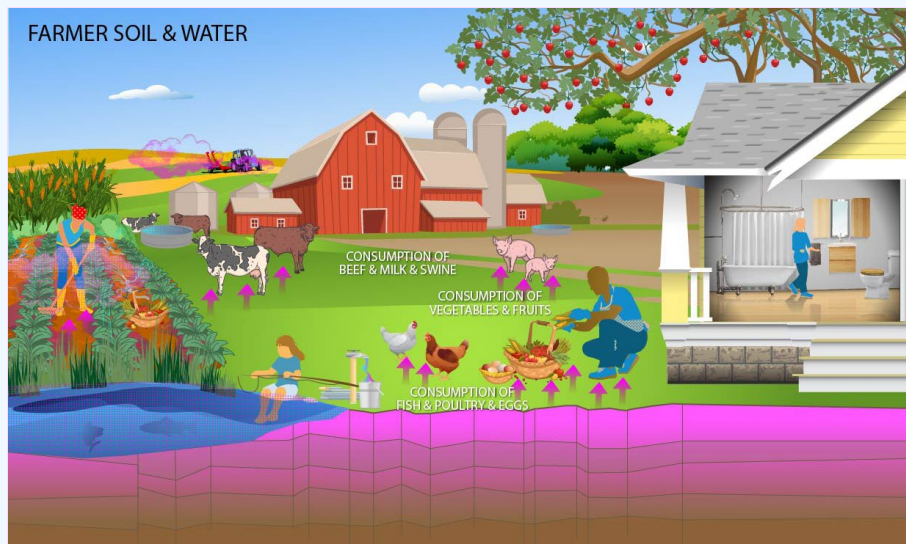
$$IFSM_{\text{far-adj}}(\text{g}) = \left(\left(EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}}(6 \text{ years}) \times IRSM_{\text{far-c}} \left(\frac{\text{g}}{\text{day}} \right) \right) + \left(EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}}(34 \text{ years}) \times IRSM_{\text{far-a}} \left(\frac{\text{g}}{\text{day}} \right) \right) \right)$$

Definitions of the input variables are in [Table 1](#).

4.8.4 Farmer Consumption of Agricultural Products - Combined Soil, Water, and Biota

The farmer scenario should be considered an extension of the resident scenario and evaluates consumption of farm products for a subsistence farmer. Like the resident, the farmer scenario assumes the receptor will be exposed via consumption of home grown produce (100% of fruit and vegetables are from the farm). In addition to produce, 100% of consumption of the following are also considered to be from the farm: beef, dairy, fin fish, shellfish, swine, egg, and poultry. All feed and water (100%) for farm products is considered to have been grown on or provided from contaminated portions of the site. For these farm products, risk-based PRGs are provided for both soil and water that may contribute contaminants to the products. The results are presented in an interactive graphic that shows the contribution from both sources. See section 4.10.6 for details. Also like the resident, age-adjusted intake equations were developed for all of the ingestion/consumption equations to account for changes in intake as the receptor ages.

Graphical Representation



PRG Equations - Only

Results of combined soil, water, and biota exposure are presented in an interactive graph. See Section 4.10.6 for details.

- consumption of fruits and vegetables. Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 9 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-grown produce.

y-INTERCEPT =

$$\text{PRG}_{\text{far-soil-produce-ing-tot}} (\text{pCi/g}) = \frac{1}{\sum_{i=1}^n \text{PRG}_{\text{far-soil-produce-ing}} (\text{pCi/g})_i}$$

and:

x-INTERCEPT =

$$\text{PRG}_{\text{far-water-produce-ing-tot}} (\text{pCi/L}) = \frac{1}{\sum_{i=1}^n \text{PRG}_{\text{far-water-produce-ing}} (\text{pCi/L})_i}$$

where:

n = total number of produce items included.

where:

$$\text{PRG}_{\text{far-produce-ing-tot}} (\text{pCi/g}) = \frac{1}{\sum_{i=1}^n \text{PRG}_{\text{far-produce-ing}} (\text{pCi/g})_i}$$

where:

n = total number of produce items included

and:

$$\text{PRG}_{\text{far-produce-ing}} (\text{pCi/g}) = \frac{\text{TR}}{\text{SF}_f \left(\frac{\text{risk}}{\text{pCi}} \right) \times \text{IF}_{\text{far-adj}} (\text{g}) \times \text{CF}_{\text{far-produce}} (\text{t})}$$

where:

$$\text{IF}_{\text{far-adj}} (\text{g}) = \left(\left(\text{EF}_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \text{ED}_{\text{far-c}} (6 \text{ years}) \times \text{IR}_{\text{far-c}} \left(\frac{\text{g}}{\text{day}} \right) \right) + \left(\text{EF}_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \text{ED}_{\text{far-a}} (34 \text{ years}) \times \text{IR}_{\text{far-a}} \left(\frac{\text{g}}{\text{day}} \right) \right) \right)$$

- **consumption of poultry.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced poultry.

$\text{PRG}_{\text{far-soil-poultry-ing}} =$

$$\text{y-INTERCEPT} = \frac{\text{PRG}_{\text{far-poultry-ing}} (\text{pCi/g})}{\text{TF}_{\text{poultry}} \left(\frac{\text{day}}{\text{kg}} \right) \times \left[\left(\text{Q}_{\text{p-poultry}} \left(\frac{0.2 \text{ kg}}{\text{day}} \right) \times f_{\text{p-poultry}} (1) \times f_{\text{s-poultry}} (1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(\text{Q}_{\text{s-poultry}} \left(\frac{0.022 \text{ kg}}{\text{day}} \right) \times f_{\text{p-poultry}} (1) \right) \right]}$$

and:

$\text{PRG}_{\text{far-water-poultry-ing}} (\text{pCi/L}) =$

$$\text{y-INTERCEPT} = \frac{\text{PRG}_{\text{far-poultry-ing}} (\text{pCi/g})}{\text{TF}_{\text{poultry}} \left(\frac{\text{day}}{\text{kg}} \right) \times \text{Q}_{\text{w-poultry}} \left(\frac{0.4 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right)}$$

where:

$$\text{SLOPE} = \frac{-\text{Q}_{\text{w-poultry}} \left(\frac{0.4 \text{ L}}{\text{day}} \right)}{\left[\text{Q}_{\text{p-poultry}} \left(\frac{0.2 \text{ kg}}{\text{day}} \right) \times f_{\text{p-poultry}} (1) \times f_{\text{s-poultry}} (1) \times (R_{\text{upp}} + R_{\text{es}}) \right] + \left[\text{Q}_{\text{s-poultry}} \left(\frac{0.022 \text{ kg}}{\text{day}} \right) \times f_{\text{p-poultry}} (1) \right]}$$

where:

$$R_{\text{upp}} = \text{Bv}_{\text{dry}} \left(\frac{\text{pCi / g-dry plant}}{\text{pCi / g-dry soil}} \right); R_{\text{es}} = \text{MLF}_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{\text{g-dry plant}} \right)$$

- **consumption of eggs.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced eggs.

$$PRG_{\text{far-soil-egg-ing}} =$$

$$y\text{-INTERCEPT} = \frac{PRG_{\text{far-egg-ing}} (\text{pCi/g})}{TF_{\text{egg}} \left(\frac{\text{day}}{\text{kg}} \right) \times \left[\left(Q_{\text{p-poultry}} \left(\frac{0.2 \text{ kg}}{\text{day}} \right) \times f_{\text{p-poultry}} (1) \times f_{\text{s-poultry}} (1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-poultry}} \left(\frac{0.022 \text{ kg}}{\text{day}} \right) \times f_{\text{p-poultry}} (1) \right) \right]}$$

and:

$$PRG_{\text{far-water-egg-ing}} (\text{pCi/L}) =$$

$$x\text{-INTERCEPT} = \frac{PRG_{\text{far-egg-ing}} (\text{pCi/g})}{TF_{\text{egg}} \left(\frac{\text{day}}{\text{kg}} \right) \times Q_{\text{w-poultry}} \left(\frac{0.4 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right)}$$

where:

$$\text{SLOPE} = \frac{-Q_{\text{w-poultry}} \left(\frac{0.4 \text{ L}}{\text{day}} \right)}{\left(Q_{\text{p-poultry}} \left(\frac{0.2 \text{ kg}}{\text{day}} \right) \times f_{\text{p-poultry}} (1) \times f_{\text{s-poultry}} (1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-poultry}} \left(\frac{0.022 \text{ kg}}{\text{day}} \right) \times f_{\text{p-poultry}} (1) \right)}$$

where:

$$R_{\text{upp}} = Bv_{\text{dry}} \left(\frac{\text{pCi / g-dry plant}}{\text{pCi / g-dry soil}} \right); R_{\text{es}} = \text{MLF}_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{\text{g-dry plant}} \right)$$

- consumption of beef. Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced beef.

$$PRG_{\text{far-soil-beef-ing}} =$$

$$y\text{-INTERCEPT} = \frac{PRG_{\text{far-beef-ing}} (\text{pCi/g})}{TF_{\text{beef}} \left(\frac{\text{day}}{\text{kg}} \right) \times \left[\left(Q_{\text{p-beef}} \left(\frac{11.77 \text{ kg}}{\text{day}} \right) \times f_{\text{p-beef}} (1) \times f_{\text{s-beef}} (1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-beef}} \left(\frac{0.5 \text{ kg}}{\text{day}} \right) \times f_{\text{p-beef}} (1) \right) \right]}$$

and:

$$PRG_{\text{far-water-beef-ing}} (\text{pCi/L}) =$$

$$x\text{-INTERCEPT} = \frac{PRG_{\text{far-beef-ing}} (\text{pCi/g})}{TF_{\text{beef}} \left(\frac{\text{day}}{\text{kg}} \right) \times Q_{\text{w-beef}} \left(\frac{53 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right)}$$

where:

$$\text{SLOPE} = \frac{-Q_{\text{w-beef}} \left(\frac{53 \text{ L}}{\text{day}} \right)}{\left(Q_{\text{p-beef}} \left(\frac{11.77 \text{ kg}}{\text{day}} \right) \times f_{\text{p-beef}} (1) \times f_{\text{s-beef}} (1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-beef}} \left(\frac{0.5 \text{ kg}}{\text{day}} \right) \times f_{\text{p-beef}} (1) \right)}$$

where:

$$R_{\text{upp}} = Bv_{\text{dry}} \left(\frac{\text{pCi / g-dry plant}}{\text{pCi / g-dry soil}} \right); R_{\text{es}} = \text{MLF}_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{\text{g-dry plant}} \right)$$

- consumption of dairy. Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced dairy.

$$PRG_{\text{far-soil-dairy-ing}} =$$

$$y\text{-INTERCEPT} = \frac{PRG_{\text{far-dairy-ing}} (\text{pCi/g})}{TF_{\text{dairy}} \left(\frac{\text{day}}{\text{L milk}} \right) \times \rho_m \left(\frac{1.03 \text{ kg}}{1 \text{ L milk}} \right)^{-1} \times \left[\left(Q_{\text{p-dairy}} \left(\frac{20.3 \text{ kg}}{\text{day}} \right) \times f_{\text{p-dairy}} (1) \times f_{\text{s-dairy}} (1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-dairy}} \left(\frac{0.4 \text{ kg}}{\text{day}} \right) \times f_{\text{p-dairy}} (1) \right) \right]}$$

and:

$$PRG_{\text{far-water-dairy-ing}} (\text{pCi/L}) =$$

$$x\text{-INTERCEPT} = \frac{PRG_{\text{far-dairy-ing}} (\text{pCi/g})}{TF_{\text{dairy}} \left(\frac{\text{day}}{\text{L milk}} \right) \times \rho_m \left(\frac{1.03 \text{ kg}}{1 \text{ L milk}} \right)^{-1} \times Q_{\text{w-dairy}} \left(\frac{92 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right)}$$

where:

$$\text{SLOPE} = \frac{-Q_{\text{w-dairy}} \left(\frac{92 \text{ L}}{\text{day}} \right)}{\left(Q_{\text{p-dairy}} \left(\frac{20.3 \text{ kg}}{\text{day}} \right) \times f_{\text{p-dairy}} (1) \times f_{\text{s-dairy}} (1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-dairy}} \left(\frac{0.4 \text{ kg}}{\text{day}} \right) \times f_{\text{p-dairy}} (1) \right)}$$

where:

$$R_{\text{upp}} = Bv_{\text{dry}} \left(\frac{\text{pCi / g-dry plant}}{\text{pCi / g-dry soil}} \right); R_{\text{es}} = MLF_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{\text{g-dry plant}} \right)$$

- **consumption of swine.** Chapter 13 of the 2011 [Exposure Factors Handbook](#) and the [2018 chapter 11 update](#) of the Exposure Factors Handbook were used to derive the intakes for home-produced swine.

$$PRG_{\text{far-soil-swine-ing}} =$$

$$y\text{-INTERCEPT} = \frac{PRG_{\text{far-swine-ing}} (\text{pCi/g})}{TF_{\text{swine}} \left(\frac{\text{day}}{\text{kg}} \right) \times \left[\left(Q_{\text{p-swine}} \left(\frac{4.7 \text{ kg}}{\text{day}} \right) \times f_{\text{p-swine}} (1) \times f_{\text{s-swine}} (1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-swine}} \left(\frac{0.37 \text{ kg}}{\text{day}} \right) \times f_{\text{p-swine}} (1) \right) \right]}$$

and:

$$PRG_{\text{far-water-swine-ing}} (\text{pCi/L}) =$$

$$x\text{-INTERCEPT} = \frac{PRG_{\text{far-swine-ing}} (\text{pCi/g})}{TF_{\text{sw}} \left(\frac{\text{day}}{\text{kg}} \right) \times Q_{\text{w-swine}} \left(\frac{11.4 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right)}$$

where:

$$\text{SLOPE} = \frac{-Q_{\text{w-swine}} \left(\frac{11.4 \text{ L}}{\text{day}} \right)}{\left(Q_{\text{p-swine}} \left(\frac{4.7 \text{ kg}}{\text{day}} \right) \times f_{\text{p-swine}} (1) \times f_{\text{s-swine}} (1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-swine}} \left(\frac{0.37 \text{ kg}}{\text{day}} \right) \times f_{\text{p-swine}} (1) \right)}$$

where:

$$R_{\text{upp}} = Bv_{\text{dry}} \left(\frac{\text{pCi / g-dry plant}}{\text{pCi / g-dry soil}} \right); R_{\text{es}} = MLF_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{\text{g-dry plant}} \right)$$

- **consumption of fin fish.** Chapters 10 and 13 of the 2011 [Exposure Factors Handbook](#) were used to derive the intakes for home-caught fin fish.

$$PRG_{\text{far-soil-finish-ing}} =$$

$$y\text{-INTERCEPT} = \frac{PRG_{\text{far-finish-ing}} (pCi/g) \times Kd \left(\frac{L}{kg}\right)}{BCF \left(\frac{\text{day}}{kg}\right)}$$

and:

$$PRG_{\text{far-water-finish-ing}} (pCi/L) =$$

$$x\text{-INTERCEPT} = \frac{PRG_{\text{far-finish-ing}} (pCi/g)}{BCF \left(\frac{L}{kg}\right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}}\right)}$$

where:

$$SLOPE = \frac{-Kd \left(\frac{L}{kg}\right)}{1000}$$

- consumption of shellfish. Table 10-9 of the 2011 [Exposure Factors Handbook](#) was used to derive the intakes for home-caught shellfish.

$$PRG_{\text{far-soil-shellfish-ing}} =$$

$$y\text{-INTERCEPT} = \frac{PRG_{\text{far-shellfish-ing}} (pCi/g) \times Kd \left(\frac{L}{kg}\right)}{BCF \left(\frac{\text{day}}{kg}\right)}$$

and:

$$PRG_{\text{far-water-shellfish-ing}} (pCi/L) =$$

$$x\text{-INTERCEPT} = \frac{PRG_{\text{far-shellfish-ing}} (pCi/g)}{BCF \left(\frac{L}{kg}\right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}}\right)}$$

where:

$$SLOPE = \frac{-Kd \left(\frac{L}{kg}\right)}{1000}$$

The following consumption routes are provided in site-specific mode only and require the user to enter their own data, as the tool only provides a transfer factor.

- consumption of goat.

$$\text{PRG}_{\text{far-soil-goat-ing}} =$$

$$y\text{-INTERCEPT} = \frac{\text{PRG}_{\text{far-goat-ing}} (\text{pCi/g})}{\text{TF}_{\text{goat}} \left(\frac{\text{day}}{\text{kg}} \right) \times \left[\left(Q_{\text{p-goat}} \left(\frac{1.27 \text{ kg}}{\text{day}} \right) \times f_{\text{p-goat}}(t) \times f_{\text{s-goat}}(t) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-goat}} \left(\frac{0.23 \text{ kg}}{\text{day}} \right) \times f_{\text{p-goat}}(t) \right) \right]}$$

and:

$$\text{PRG}_{\text{far-water-goat-ing}} (\text{pCi/L}) =$$

$$x\text{-INTERCEPT} = \frac{\text{PRG}_{\text{far-goat-ing}} (\text{pCi/g})}{\text{TF}_{\text{goat}} \left(\frac{\text{day}}{\text{kg}} \right) \times Q_{\text{w-goat}} \left(\frac{3.81 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right)}$$

where:

$$\text{SLOPE} = \frac{-Q_{\text{w-goat}} \left(\frac{3.81 \text{ L}}{\text{day}} \right)}{\left(Q_{\text{p-goat}} \left(\frac{1.27 \text{ kg}}{\text{day}} \right) \times f_{\text{p-goat}}(t) \times f_{\text{s-goat}}(t) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-goat}} \left(\frac{0.23 \text{ kg}}{\text{day}} \right) \times f_{\text{p-goat}}(t) \right)}$$

where:

$$R_{\text{upp}} = \text{Bv}_{\text{dry}} \left(\frac{\text{pCi / g-dry plant}}{\text{pCi / g-dry soil}} \right); R_{\text{es}} = \text{MLF}_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{\text{g-dry plant}} \right)$$

- consumption of goat milk.

$$\text{PRG}_{\text{far-soil-goat-milk-ing}} =$$

$$y\text{-INTERCEPT} = \frac{\text{PRG}_{\text{far-goat-milk-ing}} (\text{pCi/g})}{\text{TF}_{\text{goat-milk}} \left(\frac{\text{day}}{\text{L milk}} \right) \times \rho_m \left(\frac{1.03 \text{ kg}}{1 \text{ L milk}} \right)^{-1} \times \left[\left(Q_{\text{p-goat-milk}} \left(\frac{1.59 \text{ kg}}{\text{day}} \right) \times f_{\text{p-goat-milk}}(t) \times f_{\text{s-goat-milk}}(t) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-goat-milk}} \left(\frac{0.29 \text{ kg}}{\text{day}} \right) \times f_{\text{p-goat-milk}}(t) \right) \right]}$$

and:

$$\text{PRG}_{\text{far-water-goat-milk-ing}} (\text{pCi/L}) =$$

$$x\text{-INTERCEPT} = \frac{\text{PRG}_{\text{far-goat-milk-ing}} (\text{pCi/g})}{\text{TF}_{\text{goat-milk}} \left(\frac{\text{day}}{\text{L milk}} \right) \times \rho_m \left(\frac{1.03 \text{ kg}}{1 \text{ L milk}} \right)^{-1} \times Q_{\text{w-goat-milk}} \left(\frac{8.75 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right)}$$

where:

$$\text{SLOPE} = \frac{-Q_{\text{w-goat-milk}} \left(\frac{8.75 \text{ L}}{\text{day}} \right)}{\left(Q_{\text{p-goat-milk}} \left(\frac{1.59 \text{ kg}}{\text{day}} \right) \times f_{\text{p-goat-milk}}(t) \times f_{\text{s-goat-milk}}(t) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-goat-milk}} \left(\frac{0.29 \text{ kg}}{\text{day}} \right) \times f_{\text{p-goat-milk}}(t) \right)}$$

where:

$$R_{\text{upp}} = \text{Bv}_{\text{dry}} \left(\frac{\text{pCi / g-dry plant}}{\text{pCi / g-dry soil}} \right); R_{\text{es}} = \text{MLF}_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{\text{g-dry plant}} \right)$$

- consumption of sheep.

$$PRG_{\text{far-soil-sheep-ing}} =$$

$$y\text{-INTERCEPT} = \frac{PRG_{\text{far-sheep-ing}} (\text{pCi/g})}{TF_{\text{sheep}} \left(\frac{\text{day}}{\text{kg}} \right) \times \left[\left(Q_{\text{p-sheep}} \left(\frac{1.75 \text{ kg}}{\text{day}} \right) \times f_{\text{p-sheep}} (1) \times f_{\text{s-sheep}} (1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-sheep}} \left(\frac{0.32 \text{ kg}}{\text{day}} \right) \times f_{\text{p-sheep}} (1) \right) \right]}$$

and:

$$PRG_{\text{far-water-sheep-ing}} (\text{pCi/L}) =$$

$$x\text{-INTERCEPT} = \frac{PRG_{\text{far-sheep-ing}} (\text{pCi/g})}{TF_{\text{sheep}} \left(\frac{\text{day}}{\text{kg}} \right) \times Q_{\text{w-sheep}} \left(\frac{5.25 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right)}$$

where:

$$\text{SLOPE} = \frac{-Q_{\text{w-sheep}} \left(\frac{5.25 \text{ L}}{\text{day}} \right)}{\left(Q_{\text{p-sheep}} \left(\frac{1.75 \text{ kg}}{\text{day}} \right) \times f_{\text{p-sheep}} (1) \times f_{\text{s-sheep}} (1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-sheep}} \left(\frac{0.32 \text{ kg}}{\text{day}} \right) \times f_{\text{p-sheep}} (1) \right)}$$

where:

$$R_{\text{upp}} = Bv_{\text{dry}} \left(\frac{\text{pCi} / \text{g-dry plant}}{\text{pCi} / \text{g-dry soil}} \right); R_{\text{es}} = \text{MLF}_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{\text{g-dry plant}} \right)$$

- consumption of sheep milk.

$$PRG_{\text{far-soil-sheep-milk-ing}} =$$

$$y\text{-INTERCEPT} = \frac{PRG_{\text{far-sheep-milk-ing}} (\text{pCi/g})}{TF_{\text{sheep-milk}} \left(\frac{\text{day}}{\text{L milk}} \right) \times \rho_m \left(\frac{1.03 \text{ kg}}{1 \text{ L milk}} \right)^{-1} \times \left[\left(Q_{\text{p-sheep-milk}} \left(\frac{3.15 \text{ kg}}{\text{day}} \right) \times f_{\text{p-sheep-milk}} (1) \times f_{\text{s-sheep-milk}} (1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-sheep-milk}} \left(\frac{0.57 \text{ kg}}{\text{day}} \right) \times f_{\text{p-sheep-milk}} (1) \right) \right]}$$

and:

$$PRG_{\text{far-water-sheep-milk-ing}} (\text{pCi/L}) =$$

$$x\text{-INTERCEPT} = \frac{PRG_{\text{far-sheep-milk-ing}} (\text{pCi/g})}{TF_{\text{sheep-milk}} \left(\frac{\text{day}}{\text{L milk}} \right) \times \rho_m \left(\frac{1.03 \text{ kg}}{1 \text{ L milk}} \right)^{-1} \times Q_{\text{w-sheep-milk}} \left(\frac{10.4 \text{ L}}{\text{day}} \right) \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right)}$$

where:

$$\text{SLOPE} = \frac{-Q_{\text{w-sheep-milk}} \left(\frac{10.4 \text{ L}}{\text{day}} \right)}{\left(Q_{\text{p-sheep-milk}} \left(\frac{3.15 \text{ kg}}{\text{day}} \right) \times f_{\text{p-sheep-milk}} (1) \times f_{\text{s-sheep-milk}} (1) \times (R_{\text{upp}} + R_{\text{es}}) \right) + \left(Q_{\text{s-sheep-milk}} \left(\frac{0.57 \text{ kg}}{\text{day}} \right) \times f_{\text{p-sheep-milk}} (1) \right)}$$

where:

$$R_{\text{upp}} = Bv_{\text{dry}} \left(\frac{\text{pCi} / \text{g-dry plant}}{\text{pCi} / \text{g-dry soil}} \right); R_{\text{es}} = \text{MLF}_{\text{pasture}} \left(\frac{0.25 \text{ g-dry soil}}{\text{g-dry plant}} \right)$$

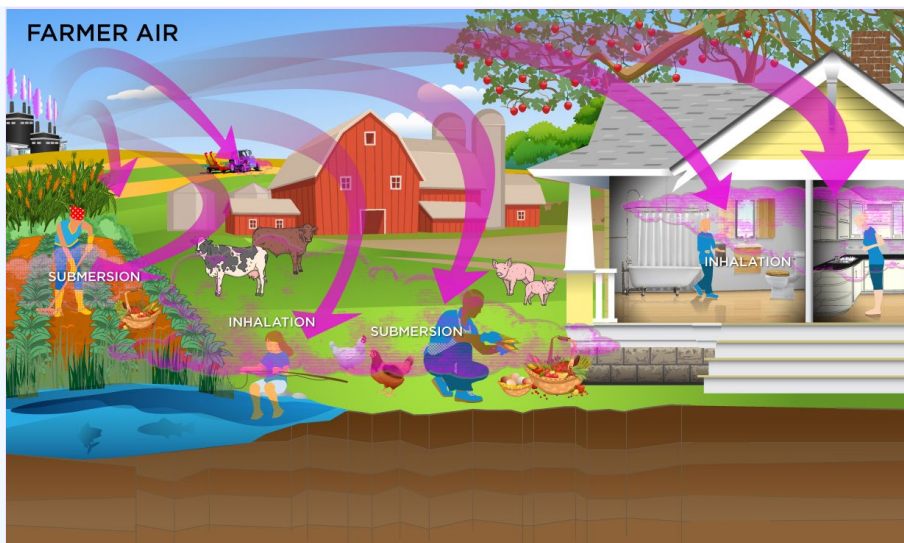
Results of combined soil, water, and biota exposure are presented in an interactive graph. See Section 4.10.6 for details.

Definitions of the input variables are in [Table 1](#).

4.8.5 Farmer Air

This receptor spends most, if not all, of the day at home except for the hours spent at work. The activities for this receptor involve typical home chores (cooking, cleaning, and laundering) as well as gardening. The resident is assumed to be exposed to contaminants via the following pathways: inhalation of ambient air and external radiation from contaminants in ambient air. To take into account the different inhalation rates for children and adults, age-adjusted intake equations were developed to account for changes in intake as the receptor ages.

Graphical Representation



PRG Equations

The resident ambient air land use equation, presented here, contains the following exposure routes without half-life decay:

- inhalation and

$$PRG_{\text{far-air-inh}} \left(\text{pCi/m}^3 \right) = \frac{TR}{SF_i \left(\frac{\text{risk}}{\text{pCi}} \right) \times IFA_{\text{far-adj}} \left(259,000 \text{ m}^3 \right)}$$

where:

$$IFA_{\text{far-adj}} \left(259,000 \text{ m}^3 \right) = \left(\left[EF_{\text{far-c}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-c}} (6 \text{ years}) \times ET_{\text{far-c}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{\text{far-c}} \left(\frac{10 \text{ m}^3}{\text{day}} \right) \right] + \left[EF_{\text{far-a}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times ED_{\text{far-a}} (34 \text{ years}) \times ET_{\text{far-a}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times IRA_{\text{far-a}} \left(\frac{20 \text{ m}^3}{\text{day}} \right) \right] \right)$$

- external exposure to ionizing radiation

$$PRG_{\text{far-air-sub}} \left(\text{pCi/m}^3 \right) = \frac{TR}{SF_{\text{sub}} \left(\frac{\text{risk/year}}{\text{pCi/m}^3} \right) \times EF_{\text{far}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{\text{far}} (40 \text{ years}) \times ET_{\text{far}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)}$$

- total

$$PRG_{\text{far-air-tot}} \left(\text{pCi/m}^3 \right) = \frac{1}{\frac{1}{PRG_{\text{far-air-inh}}} + \frac{1}{PRG_{\text{far-air-sub}}}}$$

In situations where the contaminant in the air is not being replenished (e.g., an accidental one-time air release from a factory), decay should be used. In situations where the contaminant in the air has a continual source (e.g., indoor radon from radium in the soil or an operating factory or landfill cap), the equations without decay should be used. The decay function, found in section 4.10.7, can be multiplied by the ambient air equations above to acquire ambient air PRGs with decay.

Definitions of the input variables are in [Table 1](#).

CDI Equations

The resident ambient air land use equation, presented here, contains the following exposure routes without half-life decay:

- inhalation and

- external exposure to ionizing radiation

$$CDI_{\text{far-air-sub}} \left(\text{pCi-year/m}^3 \right) = C_{\text{air}} \left(\frac{\text{pCi}}{\text{m}^3} \right) \times EF_{\text{far}} \left(\frac{350 \text{ days}}{\text{year}} \right) \times \left(\frac{1 \text{ year}}{365 \text{ days}} \right) \times ED_{\text{far}} (40 \text{ years}) \times ET_{\text{far}} \left(\frac{24 \text{ hours}}{\text{day}} \right) \times \left(\frac{1 \text{ day}}{24 \text{ hours}} \right) \times GSF_a (1.0)$$

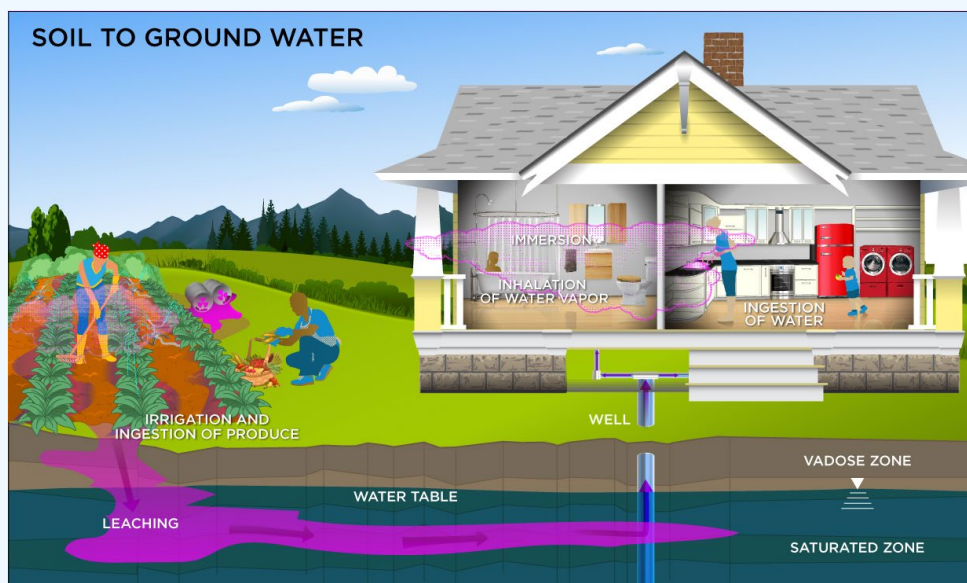
Definitions of the input variables are in [Table 1](#).

4.9 Soil to Groundwater

The soil to groundwater scenario was developed to identify concentrations in soil that have the potential to contaminate groundwater above risk based PRGs or MCLs. Migration of contaminants from soil to groundwater can be envisioned as a two-stage process: (1) release of contaminant from soil to soil leachate and (2) transport of the contaminant through the underlying soil and aquifer to a receptor well. The soil-to-groundwater scenario considers both of these fate and transport mechanisms. First, the acceptable groundwater concentration is multiplied by a dilution factor to obtain a target leachate concentration. For example, if the dilution factor is 10 and the MCL is 0.05 mg/L, the target soil leachate concentration would be 0.5 mg/L. The partition equation (presented in the Soil Screening Guidance for Radionuclides documents) is then used to calculate the total soil concentration corresponding to this soil leachate concentration.

These equations are used to calculate screening levels in soil (SSLs) that are protective of groundwater. SSLs are either back-calculated from protective risk-based groundwater concentrations or based on MCLs. The SSLs were designed for use during the early stages of a site evaluation, when information about subsurface conditions may be limited. Because of this constraint, the equations used are based on conservative, simplifying assumptions about the release and transport of contaminants in the subsurface.

Graphical Representation



PRG Equations

The user has the option to choose from two calculation methods. The first method employs the default partitioning equation for migration to groundwater. The dilution factor defaults to 20 for a 0.5-acre source. If all of the parameters needed to calculate a dilution factor are available, the user may use Method 2 (mass-limit equation for migration to groundwater).

Method 1. Partitioning Equation for Migration to Groundwater

$$SSL \left(\frac{pCi}{g} \right) = C_{\text{water}} \left(\frac{pCi}{L} \right) \times \left(\frac{kg}{1000 g} \right) \times \left(K_d \left(\frac{L}{kg} \right) + \frac{\theta_w \left(\frac{L_{\text{water}}}{L_{\text{soil}}} \right)}{\rho_b \left(\frac{kg}{L} \right)} \right)$$

where:

$$C_{\text{water}} = MCL \times DAF$$

or

$$C_{\text{water}} = PRG \times DAF$$

Method 2. Mass-Limit Equation for Migration to Groundwater

$$SSL \left(\frac{pCi}{g} \right) = \frac{C_{\text{water}} \left(\frac{pCi}{L} \right) \times i \left(\frac{m}{\text{year}} \right) \times ED_{\text{gw}} (70 \text{ years})}{\rho_b \left(\frac{kg}{L} \right) \times d_s (m) \times \left(\frac{1000 g}{kg} \right)}$$

where:

$$C_{\text{water}} = MCL \times DAF$$

or

$$C_{\text{water}} = PRG \times DAF$$

Then calculate the dilution factor using this equation.

$$\text{Dilution Attenuation Factor (DAF)} = 1 + \frac{K \left(\frac{m}{\text{year}} \right) \times i \left(\frac{m}{m} \right) \times d (m)}{i \left(\frac{0.18 m}{\text{year}} \right) \times L (m)}$$

where:

$$d (m) = \left(0.0112 \times L^2 (m) \right)^{0.5} + d_a \times \left[1 - \exp \left(\frac{-L (m) \times i \left(\frac{m}{\text{year}} \right)}{K \left(\frac{m}{\text{year}} \right) \times i \left(\frac{m}{m} \right) \times d_a (m)} \right) \right]$$

Definitions of the input variables are in [Table 1](#).

4.9.1 Conservative and Simplifying Assumptions for the Soil to Ground Water Scenario

The SSL scenario was designed for use during the early stages of a site evaluation, when information about subsurface conditions may be limited. Because of this constraint, methods 1 and 2 are based on conservative, simplifying assumptions about the release and transport of contaminants in the subsurface. These assumptions include:

- The source is infinite (i.e., steady-state concentrations will be maintained in ground water over the exposure period of interest).
- Contaminants are uniformly distributed throughout the zone of contamination.
- Soil contamination extends from the surface to the water table (i.e., adsorption sites are filled in the unsaturated zone beneath the area of contamination).
- There is no contaminant loss due to biological degradation or volatilization in the unsaturated zone.
- Equilibrium soil/water partitioning is instantaneous and linear in the contaminated soil.
- The receptor well is at the edge of the source (i.e., there is no dilution from recharge downgradient of the site) and is screened within the plume.
- The aquifer is unconsolidated and unconfined (surficial).
- Aquifer properties are homogeneous and isotropic.
- Chelating or complexing agents are not present.
- There is no facilitated transport (e.g., colloidal transport) of inorganic contaminants in aquifer.

SSLs developed using this methodology are evolving risk-based levels that can be refined as more site information becomes available. The early use of the methodology at a site will help focus further subsurface investigations on areas of true concern with respect to ground water quality and will provide information on soil characteristics, aquifer characteristics, and radionuclide properties that can be built upon as a site evaluation progresses.

4.10 Supporting Equations and Parameter Discussion

There are five parts of the above land use equations that require further explanation. The first is the explanation of the inhalation variable: the particulate emission factor (PEF). The second is the use of the radionuclide decay constant (λ). The third is the explanation of the area correction factor (ACF). The fourth is the explanation of the outdoor soil gamma shielding factor (GCF_o). The fifth is explanation of the groundwater transport portion of the equations involving the soil-to-water partition coefficient (K_d).

4.10.1 Particulate Emission Factor (PEF) and Volatilization Factor (VF)

Inhalation of isotopes adsorbed to respirable particles (PM10) was assessed using a default PEF equal to $1.36 \times 10^9 \text{ m}^3/\text{kg}$. This equation relates the contaminant concentration in soil with the concentration of respirable particles in the air due to fugitive dust emissions from contaminated soils. The generic PEF was derived using default values that correspond to a receptor point concentration of approximately $0.76 \text{ ug}/\text{m}^3$. The relationship is derived by Cowherd (1985) for a rapid assessment procedure applicable to a typical hazardous waste site, where the surface contamination provides a relatively continuous and constant potential for emission over an extended period of time (e.g., years). This represents an annual average emission rate based on wind erosion that should be compared with chronic health criteria; it is not appropriate for evaluating the potential for more acute exposures. Definitions of the input variables are in [Table 1](#).

With the exception of a few radionuclides, the PEF does not appear to significantly affect most PRGs. The equation forms the basis for deriving a generic PEF for the inhalation pathway. For more details regarding specific parameters used in the PEF model, refer to [Soil Screening Guidance for Radionuclides: Technical Background Document](#). The use of alternate values on a specific site should be justified and presented in an Administrative Record, if considered in CERCLA remedy selection.

$$\text{PEF} \left(\frac{\text{m}^3_{\text{air}}}{\text{kg}_{\text{soil}}} \right) = \left(\frac{Q}{C_{\text{wind}}} \left(\frac{\frac{\text{g}}{\text{m}^2 \cdot \text{s}}}{\frac{\text{kg}}{\text{m}^3}} \right) \times \frac{3,600 \left(\frac{\text{s}}{\text{hour}} \right)}{0.036 \times (1 - V) \times \left(\frac{U_m \left(\frac{\text{m}}{\text{s}} \right)}{U_t \left(\frac{\text{m}}{\text{s}} \right)} \right)^3} \times F(x) \right)$$

where:

$$\frac{Q}{C_{\text{wind}}} = \left(A \times \exp \left[\frac{(\ln A_s (\text{acre}) - B)^2}{C} \right] \right)$$

and:

if $x < 2$, $F(x) = 1.91207 - 0.0278085x + 0.48113x^2 - 1.09871x^3 + 0.335341x^4$

if $x \geq 2$, $F(x) = 0.18 \left(8x^3 + 12x \right) e^{-x^2}$

where:

$$x = 0.886 \times \left(\frac{U_t}{U_m} \right)$$

Note: the generic PEF evaluates wind-borne emissions and does not consider dust emissions from traffic or other forms of mechanical disturbance that could lead to greater emissions than assumed here.

EPA derived a default volatilization factor (VF) value of $17 \text{ m}^3/\text{kg}$ for tritium. The VF replaces the PEF in the PRG equations when tritium is being addressed. This VF value is based on a steady-state model that assumes--on average--tritium in soil pore water and tritium in air (as tritiated water vapor) will be distributed in the environment in proportion to the average water content in soil and air. EPA assumes a mean atmospheric humidity of 6 grams of water per cubic meter of air (g/m^3) nationwide ([Etnier 1980](#)) and an average soil moisture content of 10% (i.e., 100 grams of water per kilogram of soil). Given these assumptions, EPA calculates the VF term for tritium as:

$$\text{VFH-3} = 100 \text{ g H}_2\text{O}/\text{kg soil} / 6 \text{ g H}_2\text{O}/\text{m}^3 \text{ air}$$

$$= 17 \text{ m}^3 \text{ air}/\text{kg soil}$$

$$= 17 \text{ m}^3/\text{kg}$$

EPA believes that this value is appropriate for the average case, both outdoors and indoors. However, site managers can derive a site-specific VF term for tritium that may be more appropriate for a specific site, considering local atmospheric humidity and soil moisture content.

4.10.2 Standard Unpaved Road Vehicle Traffic Particulate Emission Factor (PEF_{sc})

The equation to calculate the subchronic particulate emission factor (PEF_{sc}) is significantly different from the resident and non-resident PEF equations. The PEF_{sc} focuses exclusively on emissions from truck traffic on unpaved roads, which typically contribute the majority of dust emissions during construction. This equation requires estimates of parameters such as the number of days with at least 0.01 inches of rainfall, the mean vehicle weight, and the sum of fleet vehicle distance traveled during construction.

The number of days with at least 0.01 inches of rainfall can be estimated using Exhibit 5-2 in the [supplemental soil screening guidance](#). Mean vehicle weight (W) can be estimated by assuming the numbers and weights of different types of vehicles. For example, assuming that the daily unpaved road traffic consists of 20 two-ton cars and 10 twenty-ton trucks, the mean vehicle weight would be:

$$W = [(20 \text{ cars} \times 2 \text{ tons/car}) + (10 \text{ trucks} \times 20 \text{ tons/truck})] / 30 \text{ vehicles} = 8 \text{ tons}$$

The sum of the fleet vehicle kilometers traveled during construction (Σ VKT) can be estimated based on the size of the area of surface soil contamination, assuming the configuration of the unpaved road and the amount of vehicle traffic on the road. For example, if the area of surface soil contamination is 0.5 acres (or 2,024 m²) and one assumes that this area is configured as a square with the unpaved road segment dividing the square evenly, the road length would be equal to the square root of 2,024 m², 45 m (or 0.045 km). Assuming that each vehicle travels the length of the road once per day, 5 days per week, for a total of 6 months, the total fleet vehicle kilometers traveled would be:

$$\Sigma \text{ VKT} = 30 \text{ vehicles} \times 0.045 \text{ km/day} \times (52 \text{ wks/yr} / 2) \times 5 \text{ days/wk} = 175.5 \text{ km}$$

$$PEF_{sc} \left(\frac{m^3_{\text{air}}}{kg_{\text{soil}}} \right) = \frac{Q}{C_{sr}} \left(\frac{\frac{g}{m^2 \cdot s}}{\frac{kg}{m^3}} \right) \times \frac{1}{F_D} \times \frac{T_t (s) \times A_R (m^2)}{2.6 \times \left(\frac{s}{12} \right)^{0.8} \times \left(\frac{W(\text{tons})}{3} \right)^{0.4} \times \left(\frac{365 \text{ (days)}}{\text{year}} - p \left(\frac{\text{days}}{\text{year}} \right) \right) \times 281.9 \times \Sigma \text{ VKT}(\text{km})}$$

$$\frac{Q}{C_{sr}} \left(\frac{\frac{g}{m^2 \cdot s}}{\frac{kg}{m^3}} \right) = A \times \exp \left[\frac{(\ln A_s (\text{acre}) - B)^2}{C} \right]$$

$$A_R (m^2) = L_R (\text{ft}) \times W_R (20 \text{ feet}) \times 0.092903 \left(\frac{m^2}{\text{feet}^2} \right)$$

$$W (\text{tons}) = \frac{(\text{number of cars} \times \frac{\text{tons}}{\text{car}} + \text{number of trucks} \times \frac{\text{tons}}{\text{truck}})}{\text{total vehicles}}$$

$$\Sigma \text{ VKT} (\text{km}) = \text{total vehicles} \times \text{distance} \left(\frac{\text{km}}{\text{day}} \right) \times EW_{cw} \left(\frac{\text{weeks}}{\text{year}} \right) \times DW_{cw} \left(\frac{\text{days}}{\text{week}} \right)$$

$$T_t (7200000 \text{ s}) = ED_{cw} (1 \text{ years}) \times EF_{cw} \left(\frac{250 \text{ days}}{\text{year}} \right) \times ET_{cw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{3600 \text{ s}}{\text{hour}} \right)$$

$$F_D (0.18584) = 0.1852 + \left(5.3537 / t_c \right) + \left(-9.6318 / t_c^2 \right)$$

$$t_c (8400 \text{ hours}) = ED_{cw} (1 \text{ years}) \times EW_{cw} \left(\frac{50 \text{ weeks}}{\text{year}} \right) \times \left(\frac{7 \text{ days}}{\text{week}} \right) \times \left(\frac{24 \text{ hours}}{\text{day}} \right)$$

4.10.3 Other Construction Activities Particulate Emission Factor (PEF'_{sc})

Other than emissions from unpaved road traffic, the construction worker may also be exposed to particulate matter emissions from wind erosion, excavation soil dumping, dozing, grading, tilling, or similar operations (PEF'_{sc}). These operations may occur separately or concurrently, and the duration of each operation may be different. For these reasons, the total unit mass emitted from each operation is calculated separately, and the sum is normalized over the entire area of contamination and over the entire time during which construction activities take place. Equation E-26 in the [supplemental soil screening guidance](#) was used.

$$PEF'_{sc} \left(\frac{m^3_{air}}{kg_{soil}} \right) = \frac{Q}{C_{sa}} \left(\frac{\left(\frac{g}{m^2 \cdot s} \right)}{\left(\frac{kg}{m^3} \right)} \right) \times \frac{1}{F_D} \times \frac{1}{\langle J_T \rangle \left(\frac{g}{m^2 \cdot s} \right)}$$

where:

$$\frac{Q}{C_{sa}} \left(\frac{\left(\frac{g}{m^2 \cdot s} \right)}{\left(\frac{kg}{m^3} \right)} \right) = A \times \exp \left[\frac{(\ln A_c (\text{acre}) - B)^2}{C} \right]$$

$$\langle J_T \rangle \left(\frac{g}{m^2 \cdot s} \right) = \frac{M_{wind}^{pc} (g) + M_{excav} (g) + M_{doz} (g) + M_{grade} (g) + M_{till} (g)}{A_{surf} (m^2) \times T_t (s)}$$

$$M_{wind}^{pc} (g) = 0.036 \times (1-V) \times \left(\frac{U_m \left(\frac{m}{s} \right)}{U_t \left(\frac{m}{s} \right)} \right)^3 \times F(x) \times A_{surf} (m^2) \times ED (\text{years}) \times 8760 \left(\frac{\text{hours}}{\text{year}} \right)$$

$$M_{excav} (g) = 0.35 \times 0.0016 \times \frac{\left(\frac{U_m \left(\frac{m}{s} \right)}{2.2} \right)^{1.3}}{\left(\frac{M_{m-excav} (\%)}{2} \right)^{1.4}} \times \rho_{soil} \left(\frac{Mg}{m^3} \right) \times A_{excav} (m^2) \times d_{excav} (m) \times N_{A-dump} \times 1000 \left(\frac{g}{kg} \right)$$

$$M_{doz} (g) = 0.75 \times \frac{0.45 \times s_{doz} (\%)^{1.5}}{(M_{m-doz} (\%))^{1.4}} \times \frac{\sum VKT_{doz} (km)}{S_{doz} \left(\frac{km}{hour} \right)} \times 1000 \left(\frac{g}{kg} \right)$$

$$M_{grade} (g) = 0.60 \times 0.0056 \times S_{grade} \left(\frac{km}{hour} \right)^{2.0} \times \sum VKT_{grade} (km) \times 1000 \left(\frac{g}{kg} \right)$$

and:

$$M_{till} (g) = 1.1 \times s_{till} (\%)^{0.6} \times A_{c-till} (\text{acres}) \times 4047 \left(\frac{m^2}{acre} \right) \times 10^{-4} \left(\frac{ha}{m^2} \right) \times 1000 \left(\frac{g}{kg} \right) \times N_{A-till}$$

where:

$$\sum VKT_{grade} (km) = A_{c-grade} (\text{acres}) \times 4047 \left(\frac{m^2}{acre} \right) \times \frac{1}{B_{t-grade} (m)} \times \frac{1}{1000 \left(\frac{m}{km} \right)} \times N_{A-grade}$$

where:

$$\sum VKT_{doz} (km) = A_{c-doz} (\text{acres}) \times 4047 \left(\frac{m^2}{acre} \right) \times \frac{1}{B_{t-doz} (m)} \times \frac{1}{1000 \left(\frac{m}{km} \right)} \times N_{A-doz}$$

$$T_t (7200000 s) = ED_{cw} (1 \text{ years}) \times EF_{cw} \left(\frac{250 \text{ days}}{\text{year}} \right) \times ET_{cw} \left(\frac{8 \text{ hours}}{\text{day}} \right) \times \left(\frac{3600 s}{\text{hour}} \right)$$

$$F_D (0.18584) = 0.1852 + \left(5.3537 / t_c \right) + \left(-9.6318 / t_c^2 \right)$$

$$t_c (8400 \text{ hours}) = ED_{cw} (1 \text{ years}) \times EW_{cw} \left(\frac{50 \text{ weeks}}{\text{year}} \right) \times \left(\frac{7 \text{ days}}{\text{week}} \right) \times \left(\frac{24 \text{ hours}}{\text{day}} \right)$$

and:

$$\text{if } x < 2, F(x) = 1.91207 - 0.0278085 x + 0.48113 x^2 - 1.09871 x^3 + 0.335341 x^4$$

$$\text{if } x \geq 2, F(x) = 0.18 (8x^3 + 12x) e^{-x^2}$$

where:

$$x = 0.886 \times \left(\frac{U_t}{U_m} \right)$$

4.10.4 Area Correction Factor

The RAGS/HHEM Part B model assumes that an individual is exposed to a source geometry that is effectively an infinite slab. The concept of an infinite slab means that the thickness of the contaminated zone and its aerial extent are so large that it behaves as if it were infinite in its physical dimensions. In practice, soil contaminated to a depth greater than about 15 cm and with an aerial extent greater than about 1,000 m² will create a radiation field comparable to that of an infinite slab (U.S. EPA 2000a).

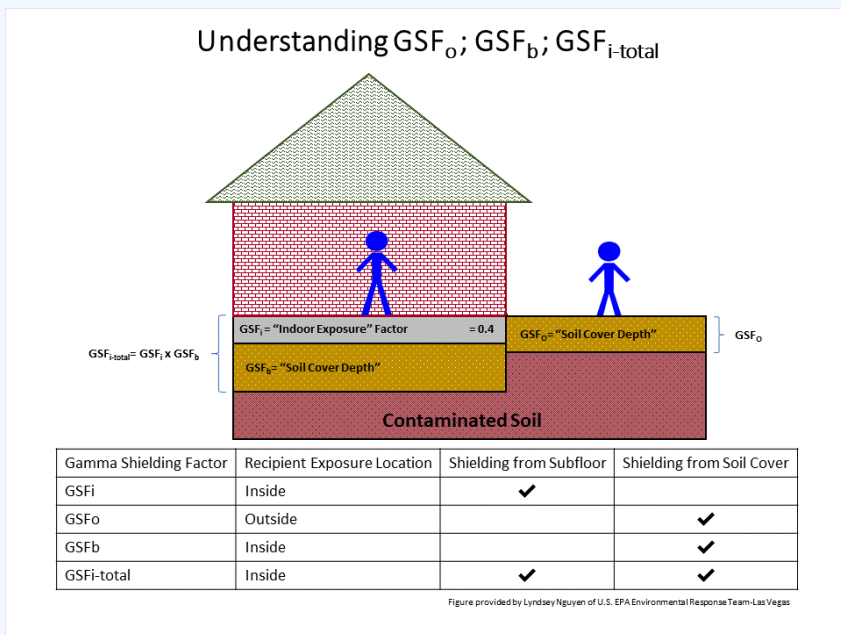
To accommodate the fact that in most residential settings the assumption of an infinite slab source will result in overly protective PRGs, an adjustment for source area is considered to be an important modification to the RAGS/HHEM Part B model. Thus, an area correction factor, ACF, has been added to the calculation of recommended PRGs. For the 2-D exposure models addressing finite areas, the ACF is made variable by isotope and area for site-specific analysis. In addition, ACFs are now available for all alternate soil analysis source depths (ground plane, 1 cm, 5 cm, and 15 cm source volumes as well as infinite source volume). This calculator allows the user to select from 19

different soil area sizes. If the default mode is selected, the ACF from the most protective area size is selected. If site-specific mode is selected, the user must select the source area. For further information on the derivation of the isotope-specific/area-specific ACF values for 2-D areas, see the [Center for Radiation Protection Knowledge ACF report](#) and [appendix](#) containing +D and +E values. For the calculation of area correction factors, a standard soil density of 1.6 g/cm³ has been used. For a description of other EPA default ACF values that predate this guidance, follow the link [here](#).

4.10.5 Gamma Shielding Factor

PRGs in this guidance are calculated without any shielding between the receptor and the source (soil). In this case, a default soil gamma shielding factor for outdoor exposure to ionizing radiation (GSF_o) is established at 1.0 (0% shielding). It is common to have some shielding (soil cover) over contaminated soil. For site-specific mode, the user must select a soil cover depth. Due to shielding, covering the contaminated area with soil will produce lower dose and risk coefficients than are stated in the Federal Guidance Report (FGR) 12 and 13. Therefore, gamma shielding factors are needed to apply the published EPA risk values to the buried contamination scenarios. Outdoor gamma shielding factors (GSF_o) are derived by modeling various thicknesses of clean soil covering ground soil contamination. The gamma shielding factor is defined as the ratio of the dose for the covered contamination to that of an unshielded surface source in soil. The MCNP output was used to derive kerma values one meter above the soil surface for various scenarios ranging from 0 cm soil cover to 100 cm soil cover in 10 cm increments while using source thicknesses of ground plane, 1, 5, and 15 cm source volumes as well as infinite source volume. Radioisotopes published in [ICRP 107](#) were considered along with decay chains of several radioisotopes. The [Center for Radiation Protection Knowledge](#) has provided GSF_o values [here](#) and an [appendix](#) containing +D and +E values. Additional source depth-specific soil gamma shielding factors (GSF) are now given for cover depths of 2 to 10 meters. The values are presented in this [appendix](#).

- A default gamma shielding factor for indoor exposure to ionizing radiation (GSF_i) is established at 0.4 (60% shielding).
- GSF_o depends on soil cover depth and is shown in equation images as GSF_{o-ext-sv}, GSF_{o-ext-1cm}, GSF_{o-ext-5cm}, GSF_{o-ext-15cm}, & GSF_{o-ext-gp}.
- In the resident, farmer, and indoor worker soil external exposure equations, GSF_{i-total} is applied to account for the gamma shielding provided by clean soil cover and the building subfloor. GSF_{i-total} = GSF_i × GSF_b; this is the product of the gamma shielding provided by the soil cover under the building (GSF_b) and the subfloor of the building (GSF_i). This accounts for all the gamma shielding during the exposure time of a resident while indoors.



- A default gamma shielding factor for exposure to ionizing radiation in air (GSF_a) is established at 1 (0% shielding).
- For the calculation of gamma shielding factors, a standard soil density of 1.6 g/cm³ has been used.

4.10.6 Using the Back-calculated to Soil and Water Graph

When multiple media are contributing to the overall site risk, it may be more practical to remediate one medium versus another. In the case of the farmer scenario, water and soil may both contribute to the risk from ingesting produce, dairy, beef, swine, poultry, eggs, fin fish, and shellfish. Sheep, sheep milk, goat, and goat milk will be available for selection in site-specific mode, provided the user is able to supply intake rate data for children and adults. The graph shows the PRGs for soil and water to achieve the target risk or target hazard index for the exposure route of concern.

The biota from both soil and water PRG results are listed after combined soil and biota and combined water and biota on the results page. The graph is available for ingestion of produce and animal products and may be accessed by clicking on any highlighted blue PRG link in the image below.

Default

Farmer PRGs for Contaminated Soil and Water - Secular Equilibrium

Isotope	Produce Slope	Produce Soil Intercept PRG	Produce Water Intercept PRG	Fish Slope	Fish Soil Intercept PRG	Fish Water Intercept PRG	Beef Slope
		TR=1E-06 (pCi/g)	TR=1E-06 (pCi/L)		TR=1E-06 (pCi/g)	TR=1E-06 (pCi/L)	
*Secular Equilibrium PRG for Am-241	-3.17E-02	8.06E-03	1.27E-02	-1.58E-01	4.67E-06	2.42E-03	-6.48E-03

Clicking on a highlighted blue biota cell for either soil or water PRG will take the user to the Farmer PRG Graphical Results page, where the graph is displayed.

The x-intercept (x,0) shows where the water PRG = Target Risk (TR) and soil concentration must equal 0. The y-intercept (0,y) shows where the soil PRG = TR and the water concentration must equal 0. Any point between (x,0) and (0,y) shows a separate PRG for water and soil that will meet the TR. The slope between the water PRG and soil PRG is provided, if the user wishes to calculate another PRG that will meet the TR.

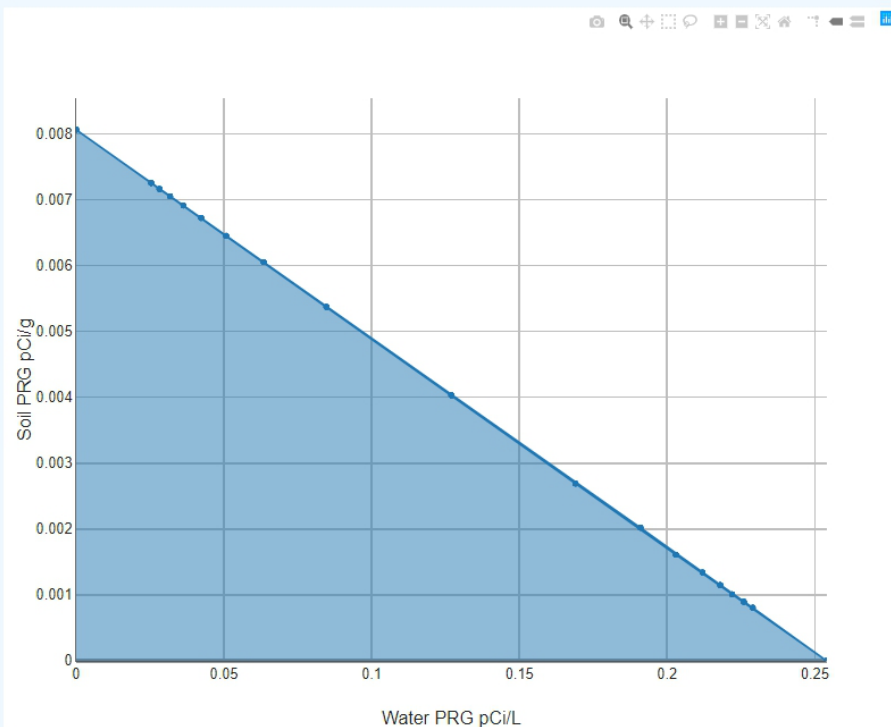
*Secular Equilibrium PRG for Am-241

Ingestion of Vegetables RISK=1.0E-06

Water PRG (x-intercept) = 2.54e-1 pCi/L

Soil PRG (y-intercept) = 8.06e-3 pCi/g

Slope = -0.031726258



The scale of the graph has been programmed with upper bounds of 1.0E+6 pCi/g and 1.0E+6 pCi/L and lower bounds of 1.0E-10 pCi/g and 1.0E-10 pCi/L solely for presentation purposes to avoid scaling issues.

The scale of the graph has been programmed with upper bounds of 1.0E+6 pCi/g and 1.0E+6 pCi/L and lower bounds of 1.0E-10 pCi/g and 1.0E-10 pCi/L, solely for presentation purposes to avoid scaling issues.

4.10.7 Radionuclide Decay Constant (λ) & Half-Life Decay Function

4.10.7.1 Radionuclide Decay Constant (λ)

The decay constant term (λ), which is based on the half-life of the isotope, is used for some media in nearly all land uses. $\lambda = 0.693/\text{half-life}$ in years (where $0.693=\ln(2)$). The term $(1 - e^{-\lambda t})$ takes into account the number of half-lives that will occur within the exposure duration to calculate an appropriate value. For the secular equilibrium PRG output option, decay is not used. In most cases, site-specific analytical data should be used to establish the actual degree of equilibrium between each parent radionuclide and its decay products in each media sampled. However, in the absence of empirical data, the secular equilibrium PRGs will provide a protective screening value. Definitions of the input variables are in [Table 1](#).

4.10.7.2 Half-Life Decay Function

In situations where the contaminant in the soil or air is not being replenished, decay should be used. An air situation that would require decay includes an accidental one-time air release from a factory. A soil situation that would require decay is a one-time dump at a landfill. In situations where the contaminant in the soil or air has a continual source (e.g., indoor radon from radium in the soil, an operating factory or landfill cap, or uranium mining), the equations without decay should be used.

- The following decay function should be multiplied by CDI equations when applicable:

$$CDI_{\text{decay}} = \left(\frac{(1 - e^{-\lambda t})}{t(\text{year}) \times \lambda \left(\frac{1}{\text{year}} \right)} \right)$$

- The following decay function should be multiplied by DCC equations when applicable:

$$\text{PRG}_{\text{decay}} = \left(\frac{t(\text{year}) \times \lambda \left(\frac{1}{\text{year}} \right)}{(1 - e^{-\lambda t})} \right)$$

4.10.8 Air Exchange Rates and Activity Equilibrium Factor (A_{eq})

When the PRG Calculator is run in site-specific mode, the air exchange rate for tapwater inhalation can be changed from the default setting. Changing the air exchange rate impacts the activity equilibrium factor (A_{eq}). The A_{eq} is defined as the ratio of progeny to parent activity concentrations at a given air exchange rate. For a straight decay chain, at zero air exchanges, the A_{eq} is equal to one and decreases as the air exchange rate increases. The A_{eq} is utilized in the PRG tapwater inhalation equations to calculate risk for inhalation only. The initial PRGs, before A_{eq} is applied, assume that the radon decay chain members are in equilibrium with each other without any air exchanges present. Therefore, the A_{eq} modifies the initial risks for inhalation by accounting for the disequilibrium between radon and its progeny due to decay and air exchanges that are present. A default value of 0.18 air exchanges per hour was selected for the resident land use from the "Update for Chapter 19 of the Exposure Factors Handbook" (U.S. EPA, 2018) for resident (Table 19-25) using the tenth percentile values. This means 90% of structures would have a higher air exchange rate and thus a lower level of progeny, which would result in less risk. A more detailed explanation of the A_{eq} derivation is presented in [ORNL 2020](#).

The image below is how the tapwater inhalation route is calculated using the A_{eq} in place of the isotopes fractional contribution (FC).

Water inhalation PRG for parent isotope:

$$\text{PRG}_{\text{water-inh-tot}} \left(\frac{\text{pCi}}{\text{L}} \right) = \frac{1}{\sum_{i=1}^n \left(\frac{\text{PRG}_{\text{water-inh}} \left(\frac{\text{pCi}}{\text{L}} \right)}{A_{\text{eq}}} \right)_i}$$

where:





n = the number of short-lived progeny;

A_{eq} = activity equilibrium factor of short-lived progeny.

5. Recommended Default Exposure Parameters

Table 1 presents the definitions of the variables and their default values. The PRG default values and exposure models are consistent with the Dose Compliance Concentrations for Radionuclides ([DCC](#)) calculator. Both the PRG and DCC calculator default values are consistent with the Regional Screening Levels for Chemical Contaminants at Superfund Sites ([RSL](#)) calculator, when the same pathways are addressed (e.g., ingestion and inhalation), and are analogous when pathways are similar (e.g., dermal and external exposure). This calculator, the DCC, and the RSL all follow the recommendations in the [OSWER Directive](#) concerning use of exposure parameters from the [2011 Exposure Factors Handbook](#). Any alternative values or assumptions used in remedy evaluation or selection on a CERCLA site should be presented with supporting rationale in Administrative Records.

Table 1. Recommended Default Exposure Parameters

Slope Factors			
Symbol 	Definition (units) 	Default 	Reference 
$SF_{\text{ext-15cm}}$	Slope Factor - external exposure (risk/yr per pCi/g)	Isotope-specific	ORNL 2014c
$SF_{\text{ext-1cm}}$	Slope Factor - external exposure (risk/yr per pCi/g)	Isotope-specific	ORNL 2014c
$SF_{\text{ext-5cm}}$	Slope Factor - external exposure (risk/yr per pCi/g)	Isotope-specific	ORNL 2014c

SF _{ext-gp}	Slope Factor - external exposure (risk/yr per pCi/cm ²)	Isotope-specific	ORNL 2014c
SF _{ext-sv}	Slope Factor - external exposure (risk/yr per pCi/g)	Isotope-specific	ORNL 2014c
SF _f	Food Ingestion Slope Factor (risk/pCi)	Isotope-specific	ORNL 2014c
SF _i	Slope Factor - inhalation (risk/pCi)	Isotope-specific	ORNL 2014c
SF _{imm}	Slope Factor - immersion (risk/yr per pCi/L)	Isotope-specific	ORNL 2014c
SF _s	Soil Ingestion Slope Factor - population (risk/pCi)	Isotope-specific	ORNL 2014c
SF _{sa}	Soil Ingestion Slope Factor - adult only (risk/pCi)	Isotope-specific	ORNL 2014c
SF _{sub}	Slope Factor - submersion (risk/yr per pCi/m ³).	Isotope-specific	ORNL 2014c
SF _w	Water Ingestion Slope Factor (risk/pCi)	Isotope-specific	ORNL 2014c

Dose and Decay Constant Variables

Symbol ▼	Definition (units) ☒	Default ☒	Reference ☒
t _{cw}	Time - construction worker (years)	1	U.S. EPA 2002b Exhibit 5-1
t _{far}	Time - farmer (years)	40	U.S. EPA 2005 (pg. C-24/C-26)
t _{iw}	Time - indoor worker (years)	25	U.S. EPA 1991a (pg. 15)
t _{ow}	Time - outdoor worker (years)	25	U.S. EPA 1991a (pg. 15)
TR	Target Risk	1 × 10 ⁻⁶	U.S. EPA 1991b
t _{rec}	Time - recreator (years)	Site-Specific	Site-Specific
t _{res}	Time - resident (years)	26	U.S. EPA 2011a, Table 16-108; 90th percentile or current residence time.
t _w	Time - worker (years)	25	U.S. EPA 1991a (pg. 15)
λ	decay constant = 0.693/half-life (year ⁻¹) where 0.693 = ln(2)	Isotope-specific	Developed for EPA's "Preliminary Remediation Goals for Radionuclide Contaminants at Superfund Sites" (NCRP 1996)

Miscellaneous Variables

Symbol ▼	Definition (units) ☒	Default ☒	Reference ☒
ACF _{ext-15cm}	Area Correction Factor - 15cm (unitless)	Isotope-specific	ORNL 2014a
ACF _{ext-1cm}	Area Correction Factor - 1cm (unitless)	Isotope-specific	ORNL 2014a
ACF _{ext-5cm}	Area Correction Factor - 5cm (unitless)	Isotope-specific	ORNL 2014a
ACF _{ext-gp}	Area Correction Factor - ground plane (unitless)	Isotope-specific	ORNL 2014a
	Area Correction Factor - soil volume		

ACF _{ext-sv}	(unitless)	Isotope-specific	ORNL 2014a
CF _{far-beef}	Beef Contaminated Fraction - farmer (unitless)	1	Developed for Radionuclide Soil Screening calculator
CF _{far-dairy}	Dairy Contaminated Fraction - farmer (unitless)	1	Developed for Radionuclide Soil Screening calculator
CF _{far-egg}	Egg Contaminated Fraction - Farmer (unitless)	1	Developed for Radionuclide Soil Screening calculator
CF _{far-fin-fish}	Fish Contaminated Fraction - farmer (unitless)	1	Developed for Radionuclide Soil Screening calculator
CF _{far-goat}	Goat Contaminated Fraction - Farmer (unitless)	1	Developed for Radionuclide Soil Screening calculator
CF _{far-goat-milk}	Goat Milk Contaminated Fraction - Farmer (unitless)	1	Developed for Radionuclide Soil Screening calculator
CF _{far-poultry}	Poultry Contaminated Fraction - farmer (unitless)	1	Developed for Radionuclide Soil Screening calculator
CF _{far-produce}	Produce Contaminated Fraction - farmer (unitless)	1	U.S. EPA 2011, U.S. EPA 2005
CF _{far-sheep}	Sheep Contaminated Fraction - Farmer (unitless)	1	Developed for Radionuclide Soil Screening calculator
CF _{far-sheep-milk}	Sheep Milk Contaminated Fraction - Farmer (unitless)	1	Developed for Radionuclide Soil Screening calculator
CF _{far-shellfish}	Fish Contaminated Fraction - farmer (unitless)	1	Developed for Radionuclide Soil Screening calculator
CF _{far-swine}	Swine Contaminated Fraction - farmer (unitless)	1	Developed for Radionuclide Soil Screening calculator
CF _{res-produce}	Produce Contaminated Fraction - resident (unitless)	1	U.S. EPA 2011, U.S. EPA 2005
GSF _a	Gamma Shielding Factor - Air (unitless)	1	Developed for Radionuclide Soil Screening calculator
GSF _b	Gamma Shielding Factor - building (unitless)	GSF _i × GSF _o	Developed for Radionuclide Soil Screening calculator
GSF _i	Gamma Shielding Factor - Indoor (unitless)	0.4	U.S. EPA 2000a. (pg. 2-22). U.S. EPA 2000b. (pg. 2-18)
GSF _{o-ext-15cm}	Gamma Shielding Factor - 15cm (unitless)	Isotope-specific	ORNL 2014b
GSF _{o-ext-1cm}	Gamma Shielding Factor - 1cm (unitless)	Isotope-specific	ORNL 2014b
GSF _{o-ext-5cm}	Gamma Shielding Factor - 5cm (unitless)	Isotope-specific	ORNL 2014b
GSF _{o-ext-gp}	Gamma Shielding Factor - ground plane (unitless)	Isotope-specific	ORNL 2014b
GSF _{o-ext-sv}	Gamma Shielding Factor - soil volume (unitless)	Isotope-specific	ORNL 2014a
K	Andelman Volatilization Factor (L/m ³)	0.5	U.S. EPA 1991b (pg. 20)
ρ _m	Density of milk (kg/L)	1.03	Watson and Tittsler 1961

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

Symbol ▼	Definition (units) ▼	Default ▼	Reference ▼
BCF	Fin Fish & Shellfish Transfer Factor (L/kg)	radionuclide-specific & species-specific	hierarchy selection in Section 2.4.2
B _{v,dry}	Soil-to-Plant Transfer Factor - dry (pCi/g-dry plant per pCi/g-dry soil)	radionuclide-specific	hierarchy selection in Section 2.4.2
B _{v,wet}	Soil-to-Plant Transfer Factor - wet (pCi/g-fresh plant per pCi/g-dry soil)	radionuclide-specific	hierarchy selection in Section 2.4.2 climate and soil selection in 2.5.1.2
F	Irrigation Period (unitless)	0.25	Personal communication
f _{p-beef}	Animal On-site Fraction - beef (unitless)	1	Developed for this calculator
f _{p-dairy}	Animal On-site Fraction - dairy (unitless)	1	Developed for this calculator
f _{p-goat}	Animal On-site Fraction - goat (unitless)	1	Developed for this calculator
f _{p-goat-milk}	Animal On-site Fraction - goat milk (unitless)	1	Developed for this calculator
f _{p-poultry}	Animal On-site Fraction - poultry (unitless)	1	Developed for this calculator
f _{p-sheep}	Animal On-site Fraction - sheep (unitless)	1	Developed for this calculator
f _{p-sheep-milk}	Animal On-site Fraction - sheep milk (unitless)	1	Developed for this calculator
f _{p-swine}	Animal On-site Fraction - swine (unitless)	1	Developed for this calculator
f _{s-beef}	Fraction of Year Animal On Site - beef (unitless)	1	Developed for this calculator
f _{s-dairy}	Fraction of Year Animal On Site - dairy (unitless)	1	Developed for this calculator
f _{s-goat}	Fraction of Year Animal On Site - goat (unitless)	1	Developed for this calculator
f _{s-goat-milk}	Fraction of Year Animal On Site - goat milk (unitless)	1	Developed for this calculator
f _{s-poultry}	Fraction of Year Animal On Site - poultry (unitless)	1	Developed for this calculator
f _{s-sheep}	Fraction of Year Animal On Site - sheep (unitless)	1	Developed for this calculator
f _{s-sheep-milk}	Fraction of Year Animal On Site - sheep milk (unitless)	1	Developed for this calculator
f _{s-swine}	Fraction of Year Animal On Site - swine (unitless)	1	Developed for this calculator
I _r	Interception Fraction (unitless)	0.42	Miller, C. W. 1980
I _r	Irrigation Rate (L/m ² - day)	3.62	Personal communication
Irr _{dep}	aerial deposition from irrigation multiplier (L/kg)	isotope-specific	Calculated
Irr _{res}	resuspension from irrigation multiplier (L/kg)	isotope-specific	Calculated
Irr _{rup}	root uptake from irrigation multiplier (L/kg)	isotope-specific	Calculated

MLF _{pasture}	Pasture Plant Mass Loading Factor (g dry soil per g dry plant)	0.25	Hinton, T. G. 1992
MLF _{produce}	Produce Plant Mass Loading Factor (g dry soil per g fresh plant)	plant-specific	See section 2.4.3 of this guide for details
P	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
Q _{p-beef}	Beef Fodder Intake Rate (kg/day)	11.77	U.S. EPA 2005 (pg. B-138)
Q _{p-dairy}	Dairy Fodder Intake Rate (kg/day)	20.3	U.S. EPA 2005 (pg. B-145)
Q _{p-goat}	Goat Fodder Intake Rate (kg/day)	1.27	4% of body weight Lyons et al. 1999
Q _{p-goat-milk}	Goat Milk Fodder Intake Rate (kg/day)	1.59	1.5% × Q _{p-goat} Lyons et al. 1999 and Tarr
Q _{p-poultry}	Chicken Fodder Intake Rate (kg/day)	0.2	U.S. EPA 2005 (pg. B-158/164)
	Duck Fodder Intake Rate (kg/day)	0.24	NRC 1994
	Turkey Fodder Intake Rate (kg/day)	0.68	NRC 1994
	Goose Fodder Intake Rate (kg/day)	0.33	NRC 1994
Q _{p-sheep}	Sheep Fodder Intake Rate (kg/day)	1.75	3.5% of body weight Lyons et al. 1999 and OMAERA
Q _{p-sheep-milk}	Sheep Milk Fodder Intake Rate (kg/day)	3.15	1.5% × Q _{p-sheep} Lyons et al. 1999 and OMAERA
Q _{p-swine}	Swine Fodder Intake Rate (kg/day)	4.7	U.S. EPA 2005 (pg. B-152)
Q _{s-beef}	Beef Soil Intake Rate (kg/day)	0.5	U.S. EPA 2005 (pg. B-139)
Q _{s-dairy}	Dairy Soil Intake Rate (kg/day)	0.4	U.S. EPA 2005 (pg. B-146)
Q _{s-goat}	Goat Soil Intake Rate (kg/day)	0.23	Handbook of Ecotoxicology (Q _s is 18% of Q _p : sheep surrogate used)
Q _{s-goat-milk}	Goat Milk Soil Intake Rate (kg/day)	0.29	Handbook of Ecotoxicology (Q _s is 18% of Q _p : sheep surrogate used)
Q _{s-poultry}	Chicken Soil Intake Rate (kg/day)	0.022	U.S. EPA 2005 (pg. B-159/165)
	Duck Soil Intake Rate (kg/day)	0.024	NRC 1994 (Q _s is 10% of Q _p)
	Turkey Soil Intake Rate (kg/day)	0.068	NRC 1994 (Q _s is 10% of Q _p)
	Goose Soil Intake Rate (kg/day)	0.033	NRC 1994 (Q _s is 10% of Q _p)
Q _{s-sheep}	Sheep Soil Intake Rate (kg/day)	0.32	Handbook of Ecotoxicology (Q _s is 18% of Q _p)
Q _{s-sheep-milk}	Sheep Milk Soil Intake Rate (kg/day)	0.57	Handbook of Ecotoxicology (Q _s is 18% of Q _p)
Q _{s-swine}	Swine Soil Intake Rate (kg/day)	0.37	U.S. EPA 2005 (pg. B-153)
Q _{w-beef}	Beef Water Intake Rate (L/day)	53	U.S. EPA 1999a (pg 10-23). U.S. EPA 1997b.
Q _{w-dairy}	Dairy Water Intake Rate (L/day)	92	U.S. EPA 1999a (pg 10-23). U.S. EPA 1997b.
Q _{w-goat}	Goat Water Intake Rate (L/day)	3.81	Tarr
Q _{w-goat-milk}	Goat Milk Water Intake Rate (L/day)	8.75	Tarr
Q _{w-poultry}	Chicken Water Intake Rate (L/day)	0.4	U.S. EPA 2005 (pg. B-159/165), NRC 1994 pg.15 (Q _w =2×Q _p)
	Duck Water Intake Rate (L/day)	0.48	NRC 1994 pg. 15 (Q _w = 2 × Q _p)
	Turkey Water Intake Rate (L/day)	1.36	NRC 1994 pg. 15 (Q _w = 2 × Q _p)
	Goose Water Intake Rate (L/day)	0.66	NRC 1994 pg. 15 (Q _w = 2 × Q _p)

$Q_{w\text{-sheep}}$	Sheep Water Intake Rate (L/day)	5.25	OMAFRA
$Q_{w\text{-sheep-milk}}$	Sheep Milk Water Intake Rate (L/day)	10.4	OMAFRA
$Q_{w\text{-swine}}$	Swine Water Intake Rate (L/day)	11.4	NEC, Swine Nutrition Guide (pg. 19). U.S. EPA 1998 (pg B-180)
R_{es}	soil resuspension multiplier (g dry soil per g fresh plant)	=MLF (pasture or produce)	Hinton 1992
R_{upp}	dry root uptake for pasture multiplier (pCi/g-dry plant per pCi/g-dry soil)	radionuclide-specific (=Bv _{dry})	hierarchy selection in Section 2.4.2
R_{upv}	wet root uptake for produce multiplier (pCi/g-fresh plant per pCi/g-dry soil)	radionuclide-specific (=Bv _{wet})	hierarchy selection in Section 2.4.2
T	Translocation Factor (unitless)	1	NCRP 1996
t_b	Long Term Deposition and Buildup (day)	10950	NCRP 1996
TF_{beef}	Beef Transfer Factor (day/kg)	radionuclide-specific	hierarchy selection in Section 2.4.2
TF_{dairy}	Dairy Transfer Factor (day/L)	radionuclide-specific	hierarchy selection in Section 2.4.2
TF_{egg}	Egg Transfer Factor (day/kg)	radionuclide-specific	hierarchy selection in Section 2.4.2
TF_{goat}	Goat Transfer Factor (day/kg)	radionuclide-specific	hierarchy selection in Section 2.4.2
$TF_{goat-milk}$	Goat Milk Transfer Factor (day/L)	radionuclide-specific	hierarchy selection in Section 2.4.2
$TF_{poultry}$	Poultry Transfer Factor (day/kg)	radionuclide-specific	hierarchy selection in Section 2.4.2
TF_{sheep}	Sheep Transfer Factor (day/kg)	radionuclide-specific	hierarchy selection in Section 2.4.2
$TF_{sheep-milk}$	Sheep Milk Transfer Factor (day/L)	radionuclide-specific	hierarchy selection in Section 2.4.2
TF_{swine}	Swine Transfer Factor (day/kg)	radionuclide-specific	hierarchy selection in Section 2.4.2
t_v	Above Ground Exposure Time (day)	60	NCRP 1996
t_w	Weathering Half-life (day)	14	NCRP 1996
Y_v	Plant Yield - wet (kg/m ²)	2	NCRP 1996
λ_B	Effective Rate of Removal from Soil (1/day)	$\lambda_{HL} + \lambda_i$	NCRP 1996
λ_E	Effective Rate of Removal from Produce (1/day)	$\lambda_i + (0.693/t_w)$	NCRP 1996
λ_{HL}	Rate of removal from soil by harvesting or leaching (1/day)	0.000027	NCRP 1996
λ_i	decay of parent or progeny (1/day)	0.693/HL (days)	NCRP 1996

Inhalation, Ingestion, and Consumption Rates





Symbol ▼	Definition (units) ☒	Default ☒	Reference ☒
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$DFA_{rec-adj}$	Recreator Immersion Factor - age-adjusted (hours)	Site-Specific	U.S. EPA 1991a (pg. 15)
$IFA_{far-adj}$	Farmer Inhalation Fraction - age-adjusted (m^3)	259,000	Calculated using the age-adjusted intake factors equation.
$IFA_{rec-adj}$	Recreator Inhalation Fraction - age-adjusted (m^3)	Site-Specific	Calculated using the age-adjusted intake factors equation.
$IFA_{res-adj}$	Resident Inhalation Fraction - age-adjusted (m^3)	161,100	Calculated using the age-adjusted intake factors equation.
$IFB_{far-adj}$	Farmer Beef Ingestion Fraction - age-adjusted (g)	3,349,850	Calculated using the age-adjusted intake factors equation
$IFD_{far-adj}$	Farmer Dairy Ingestion Fraction - age-adjusted (g)	19,456,640	Calculated using the age-adjusted intake factors equation
$IFE_{far-adj}$	Farmer Egg Intake Rate - age-adjusted (g)	1,210,580	Calculated using the age-adjusted intake factors equation
$IF_{far-adj}$	Farmer Produce Ingestion Fraction - age-adjusted (g)	plant-specific	Calculated using the age-adjusted intake factors equation
$IFFI_{far-adj}$	Farmer Fin Fish Ingestion Fraction - age-adjusted (g)	1,931,020	Calculated using the age-adjusted intake factors equation
$IFP_{far-adj}$	Farmer Poultry Ingestion Fraction - age-adjusted (g)	2,190,930	Calculated using the age-adjusted intake factors equation
$IF_{res-adj}$	Resident Produce Ingestion Fraction - age-adjusted (g)	plant-specific	Calculated using the age-adjusted intake factors equation
$IFS_{far-adj}$	Farmer Soil Ingestion Fraction - age-adjusted (mg)	1,610,000	Calculated using the age-adjusted intake factors equation.
$IFS_{far-adj}$	Farmer Shellfish Ingestion Fraction - age-adjusted (g)	2,530,640	Calculated using the age-adjusted intake factors equation
$IFS_{rec-adj}$	Recreator Soil Ingestion Fraction - age-adjusted (mg)	Site-Specific	Calculated using the age-adjusted intake factors equation.
$IFS_{res-adj}$	Resident Soil Ingestion Fraction - age-adjusted (mg)	1,120,000	Calculated using the age-adjusted intake factors equation.
$IFSW_{far-adj}$	Farmer Swine Ingestion Fraction - age-adjusted (g)	1,865,710	Calculated using the age-adjusted intake factors equation
$IFW_{rec-adj}$	Recreator Surface Water Ingestion Fraction - age-adjusted (L)	Site-Specific	Calculated using the age-adjusted intake factors equation.
$IFW_{res-adj}$	Resident Tapwater Ingestion Rate - age-adjusted (L)	19,138	Calculated using the age-adjusted intake factors equation.
IRA_{cw}	Construction Worker Soil 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)
IRA_{far-a}	Farmer Soil Inhalation Rate - adult farmer(m^3 /day)	20	U.S. EPA 1991a (pg. 15)
IRA_{far-c}	Farmer Soil Inhalation Rate - child (m^3 /day)	10	U.S. EPA 1997a (pg. 5-11)
IRA_w	Indoor Worker Soil Inhalation Rate (m^3 ; based on a rate of $2.5m^3$ /hour for 24 hours)	60	U.S. EPA 1997a (pg. 5-11)
IRA_{ow}	Outdoor Worker Soil 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)

IRA _{rec-a}	Recreator Inhalation Rate - adult (m ³ /day)	20	U.S. EPA 1991a (pg. 15)
IRA _{rec-c}	Recreator Inhalation Rate - child (m ³ /day)	10	U.S. EPA 1997a (pg. 5-11)
IRA _{res-a}	Resident Inhalation Rate - adult (m ³ /day)	20	U.S. EPA 1991a (pg. 15)
IRA _{res-c}	Resident Inhalation Rate - child (m ³ /day)	10	U.S. EPA 1997a (pg. 5-11)
IRA _w	Composite Worker Soil 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)
IRB _{far-a}	Farmer Beef Intake Rate - adult (g/day)	270.1	U.S. EPA 2011 (Table 13-33) and U.S. EPA 2018 (Table 11-5)
IRB _{far-c}	Farmer Beef Intake Rate - child (g/day)	64.6	U.S. EPA 2011 (Table 13-33) and U.S. EPA 2018 (Table 11-5)
IRD _{far-a}	Farmer Dairy Intake Rate - adult (g/day)	1,438.0	U.S. EPA 2011 (Table 13-25) and U.S. EPA 2018 (Table 11-3)
IRD _{far-c}	Farmer Dairy Intake Rate - child (g/day)	1,116.4	U.S. EPA 2011 (Table 13-25) and U.S. EPA 2018 (Table 11-3)
IRE _{far-a}	Farmer Egg Intake Rate - adult (g/day)	97.3	U.S. EPA 2011 (Table 13-40) and U.S. EPA 2018 (Table 11-7)
IRE _{far-c}	Farmer Egg Intake Rate - child (g/day)	25.1	U.S. EPA 2011 (Table 13-40) and U.S. EPA 2018 (Table 11-7)
IR _{far-a}	Farmer Produce Intake Rate - adult (g/day)	plant-specific	U.S. EPA 2011 (Table 13-31 - Table 13-57); U.S. EPA 2018 (Table 9-5)
IR _{far-c}	Farmer Produce Intake Rate - child (g/day)	plant-specific	U.S. EPA 2011 (Table 13-31 - Table 13-57); U.S. EPA 2018 (Table 9-5)
IRF _{far-a}	Farmer Fin Fish Intake Rate - adult (g/day)	155.9	U.S. EPA 2011 (Tables 10-7 and 13-20)
IRF _{far-c}	Farmer Fin Fish Intake Rate - child (g/day)	36.1	U.S. EPA 2011 (Tables 10-7 and 13-20)
IRF _{res}	Resident Fish Intake Rate (g/day)	54	U.S. EPA 1991a (page 15)
IRP _{far-a}	Farmer Poultry Intake Rate - adult (g/day)	175.5	U.S. EPA 2011 (Table 13-52) and U.S. EPA 2018 (Table 11-5)
IRP _{far-c}	Farmer Poultry Intake Rate - child (g/day)	48.8	U.S. EPA 2011 (Table 13-52) and U.S. EPA 2018 (Table 11-5)
IR _{res-a}	Resident Produce Intake Rate - adult (g/day)	plant-specific	U.S. EPA 2011 (Table 13-31 - Table 13-57); U.S. EPA 2018 (Table 9-5)
IR _{res-c}	Resident Produce Intake Rate - child (g/day)	plant-specific	U.S. EPA 2011 (Table 13-31 - Table 13-57); U.S. EPA 2018 (Table 9-5)
IRS _{cw}	Construction Worker Soil Ingestion Rate (mg/day)	330	U.S. EPA 2002b Exhibit 5-1
IRS _{far-a}	Farmer Soil Ingestion Rate - adult (mg/day)	100	U.S. EPA 1991a (pg. 15)
IRS _{far-c}	Farmer Soil Ingestion Rate - child (mg/day)	200	U.S. EPA 1991a (pg. 15)
IRSF _{far-a}	Farmer Shellfish Intake Rate - adult (g/day)	208.9	U.S. EPA 2011 (Table 10-9)
IRSF _{far-c}	Farmer Shellfish Intake Rate - child (g/day)	21.3	U.S. EPA 2011 (Table 10-9)

IRS _{IW}	Indoor Worker Soil Ingestion Rate (mg/day)	50	U.S. EPA 2001 (pg. 4-3)
IRS _{OW}	Outdoor Worker Soil Ingestion Rate (mg/day)	100	U.S. EPA 1991a (pg. 15)
IRS _{rec-a}	Recreator Soil Ingestion Rate - adult (mg/day)	100	U.S. EPA 1991a (pg. 15)
IRS _{rec-c}	Recreator Soil Ingestion Rate - child (mg/day)	200	U.S. EPA 1991a (pg. 15)
IRS _{res-a}	Resident Soil Ingestion Rate - adult (mg/day)	100	U.S. EPA 1991a (pg. 15)
IRS _{res-c}	Resident Soil Ingestion Rate - child (mg/day)	200	U.S. EPA 1991a (pg. 15)
IRS _w	Composite Worker Soil Ingestion Rate (mg/day)	100	U.S. EPA 1991a (pg. 15)
IRSW _{far-a}	Farmer Swine Intake Rate - adult (g/day)	151.1	U.S. EPA 2011 (Table 13-51) and U.S. EPA 2018 (Table 11-5)
IRSW _{far-c}	Farmer Swine Intake Rate - child (g/day)	32.2	U.S. EPA 2011 (Table 13-51) and U.S. EPA 2018 (Table 11-5)
IRW _{rec-a}	Recreator Surface Water Ingestion Rate - adult (L/hour)	0.11	Time weighted average was calculated based on the upper percentile from Table 3.7 of EFH 2019 .
IRW _{rec-c}	Recreator Surface Water Ingestion Rate - child (L/hour)	0.12	Child upper percentile from Table 3.5 of EFH 2011
IRW _{res-a}	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)
IRW _{res-c}	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

Symbol 	Definition (units) 	Default 	Reference 
DW _{cw}	Construction Worker Exposure Frequency (days/week)	5	U.S. EPA 2002b Exhibit 5-1
ED _{cw}	Construction Worker Exposure Duration (years)	1	U.S. EPA 2002b Exhibit 5-1
ED _{far}	Farmer Exposure Duration (years)	40	U.S. EPA 2005 (Table 6-3)
ED _{far-a}	Farmer Exposure Duration - adult (years)	34	U.S. EPA 1994a
ED _{far-c}	Farmer Exposure Duration - child (years)	6	U.S. EPA 2005 (Table 6-3)
ED _{IW}	Indoor Worker Exposure Duration (years)	25	U.S. EPA 1991a (pg. 15)
ED _{ow}	Outdoor Worker Exposure Duration (years)	25	U.S. EPA 1991a (pg. 15)
ED _{rec}	Recreator Exposure Duration (years)	Site-Specific	U.S. EPA 2011a, Table 16-108; 90th percentile or current residence time.
ED _{rec-a}	Recreator Exposure Duration - adult (years)	Site-Specific	-

ED _{rec-c}	Recreator Exposure Duration - child (years)	Site-Specific	U.S. EPA 1991a, Pages 6 and 15
ED _{res}	Resident Exposure Duration (years)	26	U.S. EPA 2011a, Table 16-108; 90th percentile or current residence time.
ED _{res-a}	Resident Exposure Duration - adult (years)	20	ED _{res} (26 years) - ED _{res-c} (6 years)
ED _{res-c}	Resident Exposure Duration - child (years)	6	U.S. EPA 1991a, Pages 6 and 15
ED _w	Composite Exposure Duration (years)	25	U.S. EPA 1991a (pg. 15)
EF _{ow}	Construction Worker Exposure Frequency (days/year)	250	U.S. EPA 2002b Exhibit 5-1
EF _{far}	Farmer Exposure Frequency (days/year)	350	U.S. EPA 1991a (pg. 15)
EF _{iw}	Indoor Worker Exposure Frequency (days/year)	250	U.S. EPA 1991a (pg. 15)
EF _{ow}	Outdoor Worker Exposure Frequency (days/year)	225	U.S. EPA 1991a (pg. 15)
EF _{rec}	Recreator Exposure Frequency - (days/year)	Site-Specific	U.S. EPA 1991a (pg. 15)
EF _{rec-a}	Recreator Exposure Frequency - adult (days/year)	Site-Specific	U.S. EPA 1991a (pg. 15)
EF _{rec-c}	Recreator Exposure Frequency - child (days/year)	Site-Specific	U.S. EPA 1991a (pg. 15)
EF _{res}	Resident Exposure Frequency - (days/year)	350	U.S. EPA 1991a (pg. 15)
EF _{res-a}	Resident Exposure Frequency - adult (days/year)	350	U.S. EPA 1991a (pg. 15)
EF _{res-c}	Resident Exposure Frequency - child (days/year)	350	U.S. EPA 1991a (pg. 15)
EF _w	Composite Worker Exposure Frequency (days/year)	250	U.S. EPA 1991a (pg. 15)
ET _{ow}	Construction Worker Exposure Time (hours/day)	8	Eight Hours per 24 hour Day
ET _{far}	Farmer Exposure Time (hours/day)	24	24 Hours per 24 hour Day
ET _{far-a}	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 %)
ET _{far-i}	Farmer Exposure Time - indoor (hours/day)	10.0	1440 hrs/day - (ET _{f-o} + ET _{f-a})
ET _{far-o}	Farmer Exposure Time - outdoor (hours/day)	12.167	U.S. EPA 2011 (Table 16-20 95 th %)
ET _{iw}	Indoor Worker Exposure Time (hours/day)	8	Eight Hours per 24 hour Day
ET _{ow}	Outdoor Worker Exposure Time (hours/day)	8	Eight Hours per 24 hour Day
ET _{rec}	Recreator Exposure Time (hours/day)	Site-Specific	
ET _{rec-a}	Recreator Exposure Time - adult (hours/day)	Site-Specific	

ET _{rec-c}	Recreator Exposure Time - child (hours/day)	Site-Specific	
ET _{res}	Resident Exposure Time (hours/day)	24	24 Hours per 24 hour Day
ET _{res-i}	Resident Exposure Time - indoor (hours/day)	16.416	U.S. EPA 2011 (Table 16-16 50 th %)
ET _{res-o}	Resident Exposure Time - outdoor (hours/day)	1.752	U.S. EPA 2011 (Table 16-20 50 th %)
ET _w	Composite Worker Exposure Time (hours/day)	8	Eight Hours per 24 hour Day
EV _{rec-a}	Number of bathing events per day - adult recreator (events/day)	Site-Specific	-
EV _{rec-c}	Number of bathing events per day - child recreator (events/day)	Site-Specific	U.S. EPA 1991a, Pages 6 and 15
EV _{res-a}	Number of bathing events per day - adult resident (events/day)	1	
EV _{res-c}	Number of bathing events per day - child resident (events/day)	1	
EW _{cw}	Construction Worker Exposure Frequency (weeks/year)	50	U.S. EPA 2002b Exhibit 5-1

Soil to Groundwater SSL Factor Variables

Symbol 	Definition (units) 	Default 	Reference 
C _w	Target soil leachate concentration (pCi/L)	nonzero MCL or RSL × DAF	U.S. EPA 2002b Equation 4-14
d	mixing zone depth (m)	Site-Specific	U.S. EPA 2002b Equation 4-12
d _a	aquifer thickness (m)	Site-Specific	U.S. EPA 2002b Equation 4-10
DAF	Dilution attenuation factor (unitless)	1 (or Site-Specific)	U.S. EPA 2002b Equation 4-11
d _s	depth of source (m)	Site-Specific	U.S. EPA 2002b Equation 4-10
ED _{gw}	Exposure duration	70	U.S. EPA 2002b Equation 4-14
I	Infiltration Rate (m/year)	0.18	U.S. EPA 2002b Equation 4-11
i	hydraulic gradient (m/m)	Site-Specific	U.S. EPA 2002b Equation 4-11
K	aquifer hydraulic conductivity (m/year)	Site-Specific	U.S. EPA 2002b Equation 4-11
K _d	soil-water partition coefficient (L/kg)	= K _{oc} * f _{oc} for organics	U.S. EPA 2002b Equation 4-10
L	source length parallel to ground water flow (m)	Site-Specific	U.S. EPA 2002b Equation 4-11
n	total soil porosity (L _{pore} /L _{soil})	= 1-(ρ _v /ρ _s)	U.S. EPA 2002b Equation 4-10
θ _a	air-filled soil porosity (L _{air} /L _{soil})	= n-θ _w	U.S. EPA 2002b Equation 4-10
θ _w	water-filled soil porosity (L _{water} /L _{soil})	0.3	U.S. EPA 2002b Equation 4-10
ρ _b	dry soil bulk density (kg/L)	1.5	U.S. EPA 2002b Equation 4-10
ρ _s	soil particle density (Kg/L)	2.65	U.S. EPA 2002b Equation 4-10

Wind Particulate Emission Factor Variables

Symbol ▼	Definition (units) ☒	Default ☒	Reference ☒
A	Dispersion constant unitless	PEF and region-specific	U.S. EPA 2002b Exhibit D-2
A _s	Areal extent of the site or contamination (acres)	0.5 (range 0.5 to 500)	U.S. EPA 2002b Exhibit D-2
B	Dispersion constant unitless	PEF and region-specific	U.S. EPA 2002b Exhibit D-2
C	Dispersion constant unitless	PEF and region-specific	U.S. EPA 2002b Exhibit D-2
F(x)	Function Dependent on $0.886 \times (U_t/U_m)$ (unitless)	0.194	U.S. EPA 1996, Appendix D Table 2
Q/C _{wind}	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 2002b Exhibit D-2
U _m	Mean Annual Wind Speed (m/s)	4.69	U.S. EPA 1996, Appendix D Table 2
U _t	Equivalent Threshold Value of Wind Speed at 7m (m/s)	11.32	U.S. EPA 1996, Appendix D Table 2
V	Fraction of Vegetative Cover (unitless)	0.5	U.S. EPA 2002b Equation 4-5
PEF _w	Particulate Emission Factor - Minneapolis (m ³ /kg)	1.36 x 10 ⁹ (region-specific)	U.S. EPA 2002b Exhibit D-2

Mechanical Particulate Emission Factor Variables from Standard Unpaved Road Vehicle Traffic

Symbol ▼	Definition (units) ☒	Default ☒	Reference ☒
A	Dispersion constant unitless	12.9351	U.S. EPA 2002b Equation 5-6
A _R	Surface area of contaminated road segment (m ²)	(A _R = L _R x W _R x 0.092903m ² /ft ²)	U.S. EPA 2002b Equation 5-5
A _s	Areal extent of site surface soil contamination (acres)	0.5 (range 0.5 to 500)	U.S. EPA 2002b Equation 5-6
B	Dispersion constant unitless	5.7383	U.S. EPA 2002b Equation 5-6
C	Dispersion constant unitless	71.7711	U.S. EPA 2002b Equation 5-6
F _D	Dispersion correction factor (unitless)	0.185	U.S. EPA 2002b Equation E-16
L _R	Length of road segment (ft)	Site-Specific	U.S. EPA 2002b Equation 5-5
p	Number of days with at least 0.01 inches of precipitation (days/year)	Site-Specific	U.S. EPA 2002b Exhibit 5-2
Q/C _{sr}	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 2002b Equation 5-5
T _s	Total time over which construction occurs (s)	Site-Specific	U.S. EPA 2002b Equation 5-5
W	Mean vehicle weight (tons)	(number of cars x tons/car + number of trucks x tons/truck) / total vehicles)	U.S. EPA 2002b Equation 5-5

W_R	Width of road segment (ft)	20	U.S. EPA 2002b Equation E-18
\sum_{VKT}	Sum of fleet vehicle kilometers traveled during the exposure duration (km)	\sum_{VKT} = total vehicles x distance (km/day) x frequency (weeks/year) x (days/year)	U.S. EPA 2002b Equation 5-5
PEF_{sc}	Particulate Emission Factor - subchronic (m ³ /kg)	(Site-Specific)	U.S. EPA 2002b Equation 5-5

Mechanical Particulate Emission Factor Variables from Other Construction Activities

Symbol	Definition (units)	Default	Reference
0.35	PM ₁₀ particle size multiplier (unitless)	0.35	U.S. EPA 2002b Equation E-21
0.60	PM ₁₀ scaling factor (unitless)	0.60	U.S. EPA 2002b Equation E-23
0.75	PM ₁₀ scaling factor (unitless)	0.75	U.S. EPA 2002b Equation E-22
A	Dispersion constant unitless	2.4538	U.S. EPA 2002b Equation E-15
$A_{c\text{-doz}}$	Areal extent of dozing (acres)	Site-Specific	Necessary to solve \sum_{VKT}_{doz} in U.S. EPA 2002b Equation E-22
$A_{c\text{-till}}$	Areal extent of tilling (acres)	Site-Specific	U.S. EPA 2002b Equation E-24
A_{excav}	Areal extent of excavation (m ²)	(range 0.5 to 500)	U.S. EPA 2002b Equation E-21
A_s	Areal extent of site surface soil contamination (acres)	(range 0.5 to 500)	U.S. EPA 2002b Equation E-15
A_{surf}	Areal extent of site surface soil contamination (m ²)	(range 0.5 to 500)	U.S. EPA 2002b Equation E-20
B	Dispersion constant unitless	17.5660	U.S. EPA 2002b Equation E-15
B_d	Dozer blade length (m)	Site-Specific	U.S. EPA 2002b Page E-28
B_g	Grader blade length (m)	Site-Specific	U.S. EPA 2002b Page E-28
C	Dispersion constant unitless	189.0426	U.S. EPA 2002b Equation E-15
d_{excav}	Average depth of excavation (m)	Site-Specific	U.S. EPA 2002b Equation E-21
ED	Exposure duration (years)	Site-Specific	U.S. EPA 2002b Equation E-20
F(x)	Function Dependent on $0.886 \times (U_t/U_m)$ (unitless)	0.194	U.S. EPA 1996, Appendix D Table 2
F_D	Dispersion correction factor (unitless)	Site-Specific	U.S. EPA 2002b Equation E-16
J'_T (g/m ² -s)	Total time-averaged PM ₁₀ unit emission flux for construction activities other than traffic on unpaved roads	Site-Specific	U.S. EPA 2002b Equation E-25
M_{doz}	Unit mass emitted from dozing operations (g)	Site-Specific	U.S. EPA 2002b Equation E-22
M_{excav}	Unit mass emitted from excavation soil dumping (g)	Site-Specific	U.S. EPA 2002b Equation E-21
M_{grade}	Unit mass emitted from grading operations (g)	Site-Specific	U.S. EPA 2002b Equation E-23
$M_{m\text{-doz}}$	Gravimetric soil moisture content (%)	7.9 (mean value for overburden)	U.S. EPA 2002b Equation E-22

$M_{m-excav}$	Gravimetric soil moisture content (%)	12 (mean value for municipal landfill cover)	U.S. EPA 2002b Equation E-21
M_{wind}^{PC}	Unit mass emitted from wind erosion (g)	Site-Specific	U.S. EPA 2002b Equation E-20
M_{till}	Unit mass emitted from tilling operations (g)	Site-Specific	U.S. EPA 2002b Equation E-24
N_{A-doz}	Number of times site is dozed (unitless)	Site-Specific	U.S. EPA 2002b Equation E-22
N_{A-dump}	Number of times soil is dumped (unitless)	2	U.S. EPA 2002b Equation E-21
$N_{A-grade}$	Number of times site is graded (unitless)	Site-Specific	U.S. EPA 2002b Equation E-23
N_{A-till}	Number of times soil is tilled (unitless)	2	U.S. EPA 2002b Equation E-24
Q/C_{sa}	Inverse of the ratio of the 1-h. geometric mean air concentration and the emission flux at the center of the square emission source ($g/m^2\cdot s$ per kg/m^3)	Site-Specific	U.S. EPA 2002b Equation E-15
S_{doz}	Soil silt content (%)	6.9	U.S. EPA 2002b Equation E-22
S_{doz}	Average dozing speed (kph)	11.4 (mean value for graders)	U.S. EPA 2002b Equation E-22
S_{grade}	Average grading speed (kph)	11.4 (mean value for graders)	U.S. EPA 2002b Equation E-23
S_{till}	Soil silt content (%)	18	U.S. EPA 2002b Equation E-24
U_m	Mean Annual Wind Speed (m/s)	4.69	U.S. EPA 1996, Appendix D Table 2
U_t	Equivalent Threshold Value of Wind Speed at 7m (m/s)	11.32	U.S. EPA 1996, Appendix D Table 2
V	Fraction of Vegetative Cover (unitless)	0	U.S. EPA 2002b Equation E-20
ρ_{soil}	In situ soil density (includes water) (Mg/m^3)	1.68	U.S. EPA 2002b Equation E-21
$\sum VKT_{doz}$	Sum of dozing kilometers traveled (km)	Site-Specific	U.S. EPA 2002b Equation E-22
$\sum VKT_{grade}$	Sum of grading kilometers traveled (km)	Site-Specific	U.S. EPA 2002b Equation E-23
$A_{c-grade}$	Areal extent of grading (acres)	Site-Specific	Necessary to solve $\sum VKT_{grade}$ in U.S. EPA 2002b Equation E-23
PEF'_{sc}	Particulate Emission Factor - subchronic (m^3/kg)	(Site-Specific)	U.S. EPA 2002b Equation E-26

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